THE

ELEMENTS OF MECHANISM:

CONTAINING

A FAMILIAR EXPLANATION

OF

THE CONSTRUCTION OF VARIOUS KINDS

OF

MACHINERY, &c.

For the Use of Schoolmasters and Private Students.

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ETC. ETC.

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PREFATORY NOTE.

Mechanism, as the term is usually employed, treats of the construction and relative motions of the different pieces which compose machines, without regard to the forces which may act upon them. The present work is designed to supply Elementary Teachers and Students of Engineering with a familiar exposition of the leading principles of Mechanism, and to apply them to the elucidation of the most important pieces of machinery. The most difficult investigations are printed in small type, so that these portions may be omitted by the student in reading the work for the first time.

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ELEMENTS OF MECHANISM.

CHAPTER I.

MOTION.

1. BEFORE treating of the subject of mechanism it is necessary that we should consider some of the definitions and laws of motion.

2. Motion may be either *absolute* or *relative.* When a vessel leaves the shore its motion is absolute considered in reference to some fixed point on the land; but the vessel has relative motion when its position is referred to some other vessel which is also in motion.

3. When a body moves in a straight line it is said to have a *rectilinear motion*, and when it moves in a curved line it is said to have a *curvilinear motion.*

4. When a body moves in the same path it is said to have a *continuous motion*, but if it move backwards and forwards it is said to have a *reciprocating motion.* Hence we have *reciprocating rectilinear motions* as well as *reciprocating curvilinear motions.*

5. Motion may be either uniform or variable. If a body move over equal spaces in equal times it has a uniform motion, but if it move over unequal spaces in equal times it has a variable motion.

6. The *velocity* of a body is the rate at which it moves. Thus if a man walk four miles uniformly in every hour, his velocity or rate of motion is four miles per hour; if a body move uniformly over six feet in every second, its velocity or rate of motion is six feet per second. Hence, in order to express velocity, we must have a certain number of units of

space passed over in a particular unit of time. The assumption of these units is perfectly arbitrary: however, it is customary to take a foot as the measuring unit of space, and a second as the unit of time. Hence, in the last example, we simply say that the velocity of the body is six feet.

7. When a body moves uniformly, the space passed over is equal to the product of the velocity by the time. Thus, let it be required to find the space passed over by a body in five seconds, when its velocity is seven feet per second. Here

Space passed over in 1 sec.=7 ft.

∴ " " " 5 sec.=5 times 7 ft.=35 ft.

Or, generally let s be the space, t the time in seconds, and v the velocity per second, then we have

Space passed over in 1 sec.$=v$

∴ " " t sec.$=t$ times v,

that is, $s=v\,t$ ... (1).

Which expresses the general relation of space, time and velocity, in uniform motions.

Any two of these elements being given, the remaining one may be found; thus we have

$$v=\frac{s}{t} \text{ ... (2),}$$

$$\text{and } t=\frac{s}{v} \text{ ... (3).}$$

Examples.

1. The velocity of a body is 8 ft. per sec., in what time will it move over a space of 9 yds.?

Here $v=8$, $s=9\times3=27$, and t is required, therefore, by equation (3), we have

$$t=\frac{s}{v}=\frac{27}{8}=3\tfrac{3}{8} \text{ sec.}$$

2. A body moved over 26 ft. in 5 seconds, required its velocity per second. *Ans.* $5\frac{1}{5}$ *ft.*

3. The velocity of a body is 20 miles per hour, in how many seconds will it take to move over 40 ft.?

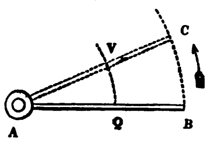
Ans. $1\frac{3}{7}$ *sec.*

8. When a body moves with a variable motion, *its velocity* at any instant, is determined by *the rate* at which it is moving at that particular instant, that is, by the space which it would move over in one second, supposing the motion which it then has to remain constant or uniform for that time. The most common case of variable motion is presented to us in the case of falling bodies. If the velocities of a body increase, it is said to be accelerated, and if the velocity decrease, to be retarded.

Angular Velocity.

9. If two wheels perform a revolution in the same time, their angular velocities are the same, no matter what may be their dimensions. If one wheel makes three revolutions in the same time that another wheel makes one, the angular velocity of the former is three times that of the latter; and so on. Let A B be a rod revolving upon A as a centre, and let it move from the position A B to A C in one second, then the length of the arc B C is the velocity of the extremity B. On A as a centre, with the radius A Q equal to unity, describe the arc Q V, cutting A C in the point V, then the length of the arc Q V is the angular velocity of the rod.

Fig. 1.



Let the length of the rod A B=5 ft., and its angular velocity Q V=2 ft., required the velocity, B C, of the extremity B.

Here A Q=1 ft., Q V= 2 ft., and A B=5 ft., then we have

arc radius 1, or Q V=2 ft.

∴ „ 5, or B C=5 times 2 ft.=10 ft.,

that is, the velocity of B=10 ft.

Or generally let A be the angular velocity, r the radius or length of the rod AB, and v the velocity of the extremity B, then we have

$$\text{arc rad. } 1 \text{ or QV} = \text{A},$$
$$\therefore \;\;\text{,,}\;\; \text{,,}\;\; r \text{ or BC} = r \text{ times A} = \text{A}r,$$
$$\text{that is, } v = \text{A}r \;\ldots\; (1),$$
$$\text{and A} = \frac{v}{r} \;\ldots\; (2).$$

10. The motion of wheels is conveniently measured by the number of rotations which they perform in a given unit of time.

Let a wheel whose radius is 3 ft., perform 20 revolutions per min., required 1st, the velocity of the circumference of the wheel, and 2nd, its angular velocity.

$$\text{circum. wheel} = 2 \times 3 \times 3{\cdot}1416$$
$$\therefore \text{ velocity circum. wheel per min.} = 2 \times 3 \times 3{\cdot}1416 \times 20$$
$$\therefore \;\;\text{,,}\;\;\text{,,}\;\; \text{per sec.} = \frac{2 \times 3 \times 3{\cdot}1416 \times 20}{60}$$
$$= 6{\cdot}2832 \text{ ft.,}$$

which is the first velocity required.

Again, the last result may be put in the following form:—

$$\text{velocity circum. wheel rad. 3 ft.} = 6{\cdot}2832 \text{ ft.}$$
$$\therefore \;\;\text{,,}\;\;\text{,,}\;\; \text{rad. 1 ft.} = \frac{6{\cdot}2832}{3} = 2{\cdot}0944 \text{ ft.}$$

Or generally let n be the number of revolutions performed by the wheel per min., and put 2π for $2 \times 3{\cdot}1416$ or the circumference of a circle whose radius is unity, the other notation being the same as in Art. 9., then we have

$$\text{circum. wheel} = 2\pi r,$$
$$\therefore \text{ velocity circum. wheel per min.} = n \text{ times } 2\pi r$$
$$= 2\pi n r,$$
$$\therefore \text{ velocity circum. wheel per sec.} = \frac{1}{30}\pi n r,$$
$$\text{that is, } v = \frac{1}{30}\pi n r \;\ldots\; (1),$$
$$\text{and } \therefore n = \frac{30v}{\pi r} \;\ldots\; (2).$$

Now eq. (1) may be written,

$$\text{velocity circum. wheel rad. } r = \frac{1}{30}\pi n r$$

$$\therefore \quad \text{,,} \quad \text{,,} \quad \text{,, rad. } 1 = \frac{1}{20}\pi n,$$

$$\text{that is, } A = \frac{1}{30}\pi n \ldots (3),$$

$$\text{and } \therefore n = \frac{30A}{\pi} \ldots (4).$$

CHAP. II.

MACHINES IN GENERAL.

11. ADVANTAGES AND USES OF MACHINES.—The following are some of the most obvious advantages and uses of machinery:—

1. In accumulating power, or exerting forces too great for human power. With the coining engine a single man can produce the impression of the die upon the metal, which the unaided pressure, exerted by a hundred men, could not effect. With the common crane one man can raise a weight which would require several horses to draw.

2. In regulating the distribution of power and motion. Uniformity in the rate of a machine is in many cases essential to its successful application. The *pendulum* of a clock, the *governors* of steam engines and water-mills, &c., are examples of regulators of power and motion.

3. In increasing or decreasing velocity. In the common spinning-wheel, the foot applied to the treadle, can only be conveniently moved with a certain speed, but a much greater motion must be given to the part which twists the flax. Again, in the common smoke-jack, the motion communicated to the vane wheel is much too great for the purpose required

this motion is therefore transmitted through a series of wheels which reduce it to the requisite speed.

4. In changing the direction of motion. By turning the handle of a windlass, a man raises a bucket from a well. The piston of a steam-engine moves up and down in a vertical direction, or, in other words, it has a reciprocating rectilinear motion, but by the intervention of mechanism this motion is made to turn wheels, to pump water, or in fact to produce the various kinds of motion required in our arts and manufactories.

5. In prolonging the action of forces. The few seconds which we take in winding up a watch, are sufficient, by the aid of wheels, to produce a force which will continue in action for 24 hours.

6. In registering operations. Familiar examples of this are exhibited in the turn-stile of our bridge keepers, and in the gas-meter.

7. In effecting a uniformity and precision in the work to be done. With the lathe an ordinary workman can turn a piece of metal perfectly cylindrical, which would baffle the skill of the most perfect mechanic to produce without the aid of such machinery.

8. In economising time and labour. Twenty years ago, the stage coach took 25 hours in travelling from London to York, but by the railway carriage the journey may be performed in one-fifth of that time. The steam printing press is another remarkable instance of the same kind.

12. Application of Forces to Machines.—Forces, applied to give motion to machinery, are developed by various means:—1. By animals. 2. By the descent of weights. 3. By the fall of water. 4. By the action of springs. 5. By the expansion and pressure of fluids. 6. By electricity and magnetism.

These forces have four modes of action:—1. In the form of simple pressure, as in the case of pressure applied to the arm of a lever, or when a fluid acts upon a piston. 2. In the form of a thrust or push, as in the case of a rod being pushed forward to give motion to another rod or some other piece of mechanism. 3. In the form of a drawing or pulling force, as in the case of wheels being moved by cords or straps. 4. In the form of a stroke, as in the case of a wedge being struck by a mallet.

The nature of the mechanism depends in some measure upon the manner in which the forces are applied to the machine. Thus, when the foot is used to turn a lathe, the force is applied to a foot-board or treadle; when a horse is employed to raise coals from a pit, the animal is made to run in a circular path, and thus motion is given to a large horizontal drum wheel round which the pit rope coils. In the first instance a vertical reciprocating motion is converted, by the intervening mechanism, into a continuous circular motion: and, in the last instance, a circular horizontal motion is converted into a rectilinear vertical one.

13. THE PARTS OF A MACHINE.—A machine consists of three important parts:—1. The parts which receive the *work* of the moving power,—these may be called RECEIVERS of work. 2. The parts which perform the work to be done by the machine,—these may be called WORKING PARTS or more simply OPERATORS. 3. The mechanism which transmits the work from the receivers to the working parts or operators,—these pieces of mechanism may be called COMMUNICATORS of work.

The form of the mechanism or communicators must always be determined from the relation subsisting between the motions of the receivers and operators.

14. RECEIVERS AND OPERATORS.—If there were no loss of work in transmission (from friction, &c.), the work applied to the receiver would always be equal to the work done by the operator.* Thus let P be the lbs. pressure applied to the receiver, and S the space in feet which it

* See the author's "Exercises on Mechanics," &c.

moves over in a certain time; P_1 the lbs. pressure produced at the working part, and S_1 the space in feet which it moves over in the same time; then neglecting the loss of work by friction, we have

$$\text{Work applied to the receiver} = P \times S,$$

$$\text{Work done upon the operator} = P_1 \times S_1;$$

$$\therefore P \times S = P_1 \times S_1 \dots (1).$$

However, it must be borne in mind that the actual or useful work done by a machine is always a certain fractional part of the work applied; this fraction determined for any particular machine is called the modulus of that machine. If m be put for this modulus, then we have from eq. (1)

$$m \times P \times S = P_1 \times S_1 \dots (2).$$

In treating of the motion of these parts of a machine it is frequently most convenient to find an expression for their proportional velocities. Thus let the receiver move over 12 ft. while the operator moves over 3 ft., then their velocity ratio is expressed by $\frac{12}{3}$, that is, in this case the receiver moves with three times the speed of the operator. Or generally let V and v be the respective velocities, then $\frac{V}{v}$ is their velocity ratio. It will be observed, that this velocity ratio is not effected by the actual velocities of the parts. In ordinary machines the velocity ratio is constant, or, in other words, it remains the same for all positions of the machinery.

In expression (1), S may be taken as the velocity of the power, and S_1 that of the resistance; hence eq. (1) becomes

$$P \times \text{velo. } P = P_1 \times \text{velo. } P_1,$$

$$\therefore \frac{\text{velo. } P}{\text{velo. } P_1} = \frac{P_1}{P} \dots (3).$$

Now $\frac{P_1}{P}$, or the resistance to be overcome divided by the power applied, is called the advantage gained by the machine, and moreover $\frac{\text{velo. P}}{\text{velo. P}_1}$ is the velocity ratio of the moving point to the working point, or, in other words, the number of times that the velocity of the resistance is contained in the velocity of the power; hence irrespective of friction, &c., THE ADVANTAGE GAINED BY A MACHINE IS EQUAL TO THE VELOCITY OF THE POWER DIVIDED BY THE VELOCITY OF THE RESISTANCE. This is called *the principle of virtual velocities.* Workmen express this law by saying, "what you gain in power you lose in speed." It will be instructive to consider the motion of machines in this simple aspect.

15. ELEMENTARY FORMS OF MECHANISM.—These consist of the following forms or pieces:—

1. *Jointed Rods* or *Link-work*, producing *lever-motions.*
2. *Straps, cords,* or *chains,* producing motion by wrapping contact, *cord-motions.*
3. *Wheel-work*, producing by rolling contact, *wheel-motions.*
4. *Sliding pieces,* producing by sliding contact, *sliding-motions* or *wedge-motions.*

The classification of the elementary pieces of mechanism here adopted, is only another aspect of *the five mechanical powers.* Thus No. 1. embraces *the lever;* No. 2. *the pulley;* No. 3. *the wheel and axle;* and No. 4. *the incline-plane and screw.*

The following may also be regarded as an element of mechanism:—

5. *Fluids,* producing motions by the distribution of pressure on surfaces.

CHAP. III.

ELEMENTARY FORMS OF MECHANISM.

LINK-WORK, PRODUCING LEVER-MOTIONS.

16. LET PW be an inflexible rod or lever, turning upon the fixed centre C, and acted upon by the pressures P and W applied perpendicularly to the lever. Now when the lever comes to the position $p\,w$, the power P has moved over the arc Pp, while the weight W has moved over the arc Ww; these arcs, therefore, respectively represent the velocities of P and W.

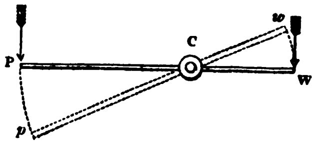


Fig. 2.

Here if the arm CP were double the arm CW, the velocity of P would be double that of W, for a double radius would sweep over a double arc.

Again, let CP$=5$ ft., and CW$=3$ ft.

In this case P describes an arc whose radius is 5 ft., while W describes an arc whose radius is 3 ft.

Suppose W to move over 3 ft., then

$$\text{velo. W, or length arc rad. } 3=3,$$
$$\therefore \text{ length arc rad. } 1=\tfrac{3}{3}=1,$$
$$\therefore \text{ velo. P, or length arc rad. } 5=5 \text{ times } 1=5,$$

that is to say, the velocity of P is to that of W as 5 is to 3, or $\frac{\text{velo. P}}{\text{velo. W}}=\frac{5}{3}$.

To find, in this example, the relation of P and W when equilibrium takes place.

Here, while P moves through 5 ft., W moves through 3 ft., hence we have

$$\text{Work of P}=\text{P}\times 5,\ \text{work of W}=\text{W}\times 3.$$
$$\therefore\ \text{P}\times 5 \doteq \text{W}\times 3.$$

Now 5 is the length of the arm CP, and 3 that of CW, therefore, in this case, we have

$$P \times CP = W \times CW.$$

17. Generally the velocity ratio of P to W will be the same as the ratio of P*p* to W*w*, or what is the same thing, as CP to CW, hence we have

$$\frac{\text{velocity } P}{\text{velocity } W} = \frac{\text{arc } Pp}{\text{arc } Ww} = \frac{CP}{CW} \dots (1).$$

Thus it appears, that *the velocity ratio of the power and weight is the same as the ratio of the lengths of the arms by which they respectively act.*

18. To find the relation of P and W, when equilibrium takes place. Here, while the power P moves over the space P*p*, the weight W moves over W*w*; hence we have

$$\text{Work of } P = P \times Pp, \text{ and work of } W = W \times Ww,$$

$$\therefore P \times Pp = W \times Ww;$$

but P*p* is the velocity of P, and W*w* the velocity of W,

$$\therefore P \times \text{velo. } P = W \times \text{velo. } W,$$

$$\therefore \frac{\text{velo. } P}{\text{velo. } W} = \frac{W}{P};$$

hence we have by eq. (1), Art. **17.**,

$$\frac{W}{P} = \frac{CP}{CW},$$

$$\text{or } P \times CP = W \times CW \dots (1);$$

that is, *the power multiplied by the units in its arm is equal to the weight multiplied by the units in its arm.*

The product P × CP is called the moment of P, and W × CW the moment of W; hence, *when equilibrium takes place in a lever, the moment of the power is equal to the moment of the weight.*

19. Levers are divided into three kinds according to the relative positions of the power and weight with respect to the fulcrum.

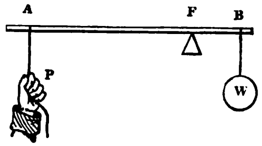


Fig. 3.

Fig. 3. represents a lever of the first kind, where the power P and weight W act on opposite sides of the fulcrum F.

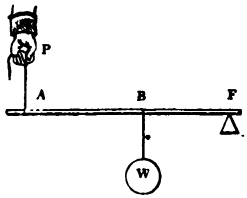


Fig. 4.

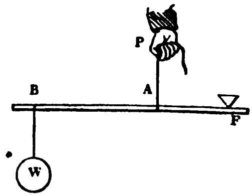


Fig. 5.

Fig. 4. represents a lever of the second kind, where the power P and weight W act on the same side of the fulcrum F, but W is nearer to the fulcrum than P.

Fig. 5. represents a lever of the third kind, where the power P and weight W act on the same side of the fulcrum F, but P is, in this case, nearer to the fulcrum than W.

The velocity ratio given in eq. (1), Art. **17.**, as well as the equation of equilibrium given in eq. (1), Art. **18.**, apply to all these cases of levers; thus we have

$$\frac{\text{velocity A}}{\text{velocity B}}=\frac{\text{FA}}{\text{FB}},$$

$$\text{and } \text{P}\times\text{FA}=\text{W}\times\text{FB}.$$

20. *To find the velocity ratio, &c.* in a system of rods or levers AB, BD, DE, turning upon the fixed centres of motion C, Q, R.

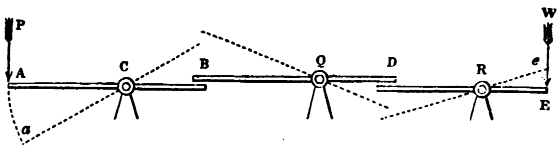


Fig. 6.

Let RE=2, RD=8, QD=3, QB=6, CB=4, and CA=12.

Here the arm RE is 2, and RD is 8; therefore RD is 4 times RE, and consequently the velocity of the point D is 4 times that of E. Let the velocity of the point E be unity then the velocity of D will be 4.

In like manner, the velocity of the point B is 2 times that of D, for the arm QB is double the arm QD; but the velocity of D is 4, therefore the velocity of B is 2 times 4, or 8.

Again the velocity of A is 3 times the velocity of B, for the arm CA is 3 times the arm CB; but the velocity of B is 8, therefore the velocity of A is 3 times 8, or 24. Hence it appears that the velocity of A is 24 times the velocity of E. Let A move over the arc A*a*, and E over the arc E*e*, then A*a* is 24 times E*e*.

Collecting these operations, we have

$$\frac{\text{velo. A}}{\text{velo. E}}=\frac{\text{RD}}{\text{RE}}\times\frac{\text{QB}}{\text{QD}}\times\frac{\text{CA}}{\text{CB}}=\frac{8}{2}\times\frac{6}{3}\times\frac{12}{4}=\frac{24}{1}.$$

From this investigation it appears, *that the velocity ratio of* P *and* W, *is found by taking the product of the lengths of the arms lying towards* P, *and dividing by the product of those lying towards* W.

For the angular velocities of A and E, we have

$$\text{ang. velo. E}=\frac{\text{arc E}e}{\text{RE}}=\frac{1}{2}$$

$$\text{ang. velo. A}=\frac{\text{arc A}a}{\text{CA}}=\frac{24}{12}=2;$$

$$\therefore\ \frac{\text{ang. velo. A}}{\text{ang. velo. E}}=\frac{2}{\frac{1}{2}}=4;$$

that is to say, the angular velocity ratio is 4.

And for the equation of equilibrium, we have eq. (3), Art. **14**., advantage gained, or $\frac{\text{W}}{\text{P}}=\frac{\text{velo. P}}{\text{velo. W}}=\frac{24}{1}$.

21. The arrangement of levers may take the form shown in the annexed cut; where the levers belong to the second kind. AC and B_1Q are connected by the link BB_1, and B_1Q and D_1R by the link DD_1. Here, as in the last case, we have

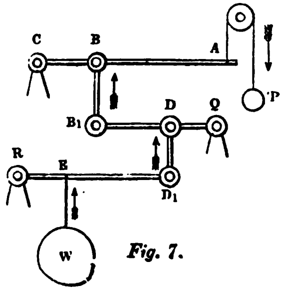


Fig. 7.

$$\frac{\text{velo. P}}{\text{velo. W}}=\frac{\text{RD}_1}{\text{RE}}\times\frac{\text{QB}_1}{\text{QD}}\times\frac{\text{CA}}{\text{CB}}.$$

22. The levers or links may be in different plans as shown in *fig.* 8.; where AB is an axis turning freely on the pivots at A and B; CD and EF are arms or levers attached to the axis. A pressure P applied to the extremity D of the arm CD will produce a motion in the extremity F of the arm EF in the direction FW. If CD and EF are perpendicular to the axis AB, then

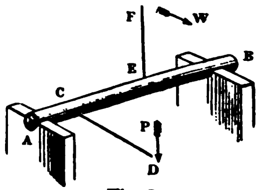


Fig. 8.

$$\frac{\text{velo. D}}{\text{velo. F}}=\frac{\text{CD}}{\text{EF}}.$$

23. In the bent lever PCW, turning on the centre C, the velocity of P will be to the velocity of W in the ratio of the circumference of the circle PK to the circumference of the circle WB, or what is the same thing, in the ratio of CP to CW.

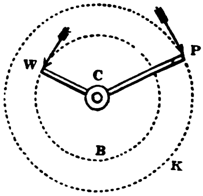


Fig. 9.

If the pressures P and W be applied perpendicularly to their respective arms, then we have for the condition of equilibrium, P × velo. P = W × velo. W, or P × CP = W × CW.

24. *To find the Velocity ratio in the link-work of fig.* 10.

Where ABC is a bent lever turning on the fixed centre B; CD a link, with joints at C and D, connecting the extremity of the lever DF with C; this lever turns on its fixed centre E, and has a forked extremity F, which gives a vertical motion to the rod GFK, which is constrained to move in this direction by guides G and K in the form of rollers.

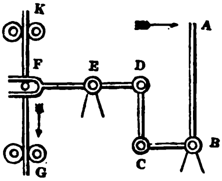


Fig. 10.

Here the arm BA has the same angular motion as the arm

BC, and the extremity D of the lever DF has the same velocity as the extremity C of the arm BC.

Let EF=2, ED=4, BC=3, and BA=12. Suppose the rod FG or the point F to have a velocity of unity.

The velocity of D is 2 times the velocity of F, for the arm ED is 2 times the arm EF; but the velocity of F is 1, therefore the velocity of D is 2, and the velocity of C is also 2.

The velocity of A is 4 times the velocity of C, for the arm BA is 4 times the arm BC; but the velocity of C is 2, therefore the velocity of A is 4 times 2, or 8. Thus it appears, that the velocity of A is 8 times the velocity of F.

Or generally, the velocity of D is $\frac{ED}{EF}$ times the velocity of F; but the velocity of F is 1, therefore the velocity of D or C is $\frac{ED}{EF}$.

The velocity of A is $\frac{BA}{BC}$ times the velocity of C; but the velocity of C is $\frac{ED}{EF}$; therefore the velocity of A is $\frac{BA}{BC}$ times $\frac{ED}{EF}$ or $\frac{BA}{BC}\times\frac{ED}{EF}$. Thus it appears that the velocity of A is $\frac{BA}{BC}\times\frac{ED}{EF}$ times the velocity of F; that is,

$$\frac{\text{velo. A}}{\text{velo. F}}=\frac{BA}{BC}\times\frac{ED}{EF}.$$

Adopting the preceding data, we have

$$\frac{\text{velo. A}}{\text{velo. F}}=\frac{12}{3}\times\frac{4}{2}=8, \text{ as before.}$$

Oblique Lever.

25. A lever AB, turning on the centre C, is acted upon by the forces P and W, in the directions TAQ and SBR; it is required to find the velocity of P and W when the lever is turned very little round.

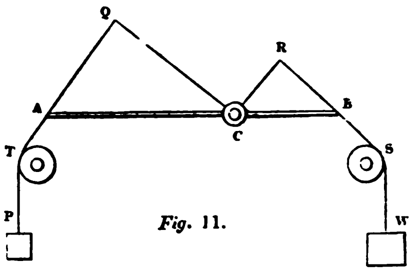


Fig. 11.

From C let fall the perpendiculars CQ and CR upon the respective directions of the forces P and W; and conceive the cords to be fixed at Q and R. Now as the lever is turned round, the points Q and R will describe arcs of circles, and P will have the same velocity as the point Q, and W the same as the point R; but these arcs are to each other in the ratio of their radii CQ, CR; and the velocities of P and W will obviously be to each other as the respective lengths of these arcs, or what is the same thing, as their radii CQ and CR. Thus if CQ be 3 times CR, then the velocity of P will be 3 times the velocity of W; or generally the velocity of P will be as many times that of W as the length of CQ is that of CR, or

$$\frac{\text{velo. P}}{\text{velo. W}}=\frac{\text{CQ}}{\text{CR}},$$

which is the velocity ratio of P, W.

And for the condition of equilibrium, let CQ=12 ft., and CR=3 ft., then the velocity of P will be 4 times that of W; that is, if we take the velocity of W=3 ft., then velocity P= 4 times 3 ft.=12 ft.

$$\therefore \text{ work of P}=\text{P}\times 12, \text{ and work of W}=\text{W}\times 3;$$

$$\therefore \text{P}\times 12=\text{W}\times 3,$$

but 12 is the length of the perpendicular CQ, and 3 that of CR,

$$\therefore \text{P}\times\text{CQ}=\text{W}\times\text{CR}.$$

The product of any force by the perpendicular on its direction is called the moment of that force: hence the moment of P is equal to the moment of W.

26. Let CP and DA be two rods, turning on the centres C and D, connected by the link BA (see cut, Art. **31.**). If the rods be moved very little from their present position, the points Q and R will have the same velocity; let this velocity be 1, and let CQ=6, and DR=3; then the angular velocity of $CP = \frac{1}{CQ} = \frac{1}{6}$, and that of $DA = \frac{1}{DR} = \frac{1}{3}$: therefore, in this case, the angular velocity of DA will be double that of CP.

Cranks.

27. A rotatory motion may be communicated to an axis by means of links; the most simple instance of this kind occurs in the single crank and connecting rod. C is an axis to which wheels or any other kind of mechanism may be attached; CD a link or arm, called a *crank*, fixed to the axis C, and having a joint at D to which the *connecting rod* DA is attached. Now if an up and down motion be given to DA, the extremity D of the crank will move in a circle, and thus a continuous rotation will be given to the axis C. When the crank arrives at the position C*n*, where it is in the same line with the connecting rod, it is said to be in one

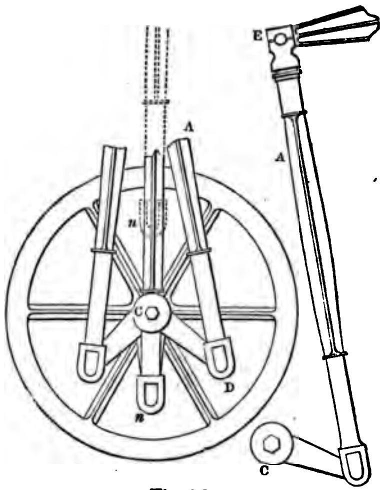


Fig. 12.

of its dead points, for then the pressure upon the connecting rod has no effect in turning the crank; but in general the inertia of the machinery and fly-wheel F carries the crank beyond the dead points. It will be seen, that the crank has to pass over two dead points in the course of one revolution. In order to avoid this irregularity in the action of the connecting rod, two cranks are sometimes placed, on the same axis, at right angles to each other. The connecting rod, in a steam engine, is usually attached to the extremity E of the great beam.

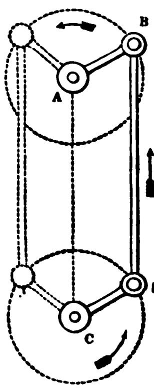


Fig. 13.

28. *Fig.* 13. shows how a rotation of the axis C is communicated to another axis A. Here the cranks CD and AB are of equal length, and the connecting rod DB is equal to CA the distance between the two centres of motion. In all positions of the mechanism, the figure CDBA will be a parallelogram, and the velocity of B will always be equal to the velocity of D. It is also obvious, that two sets of cranks may be placed upon the axes, having the corresponding cranks at right angles to each other. The advantage of this arrangement consists in having a constant moving pressure kept up, by which means the motion is sustained without the aid of the inertia of the machinery. This contrivance is more fully represented in *fig.* 14.; where the cranks *a*, *b*, *c*, and *d* are formed by bendings or loops made in the axes AB and CD, which must obviously be parallel to each other, and the connecting rods *ab* and *dc* must be of equal length.

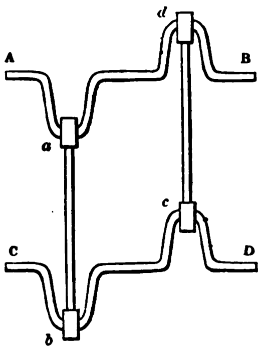


Fig. 14.

29. *Fig.* 15. represents a common application of the crank; where A is a wheel whose axis is C, to which a continuous rotation is given by means of the crank CD, the connecting rod DB, and a foot-board FB. This foot-board turns upon F as a centre, and is connected with the extremity B of the rod DB by means of joint, or it may be by a simple hook and loop. When the foot of the operator is pressed, for an instant, upon FB the crank is turned round, and the inertia of the wheel carries it round to the first position, shown in the figure; then the pressure is again applied, and so on to any series of rotations.

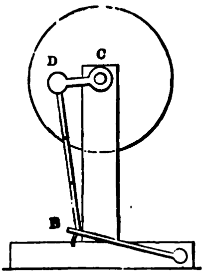


Fig. 15.

Bent Lever.

30. The property of the bent lever given in Art. **25.** may be derived more strictly as follows:

The bent lever ACB turns upon its centre C, by the action of the forces P and W applied obliquely to the arms CA and CB: it is required to find the velocity ratio of the motion of P and W, estimated in their respective lines of action AP and BW. Let CQ and CR be perpendiculars from the centre of motion C, upon the directions of the forces, and let the lever ACB be moved into the new position *acb* very near to the first. From *a* let fall *ae* perpendicular to PA produced; then while the extremity A of the arm CA describes the arc A*a*, the force P will have moved, in the line of its action, through A*e*. Now when the change of position is indefinitely small, the circular arc A*a* becomes a straight line perpendicular to CA, and A*ea* is a right-angled triangle; moreover, if A*a* be the velocity of the extremity of the arm CA, the velocity of P, in the direction P*e*, will be A*e*.

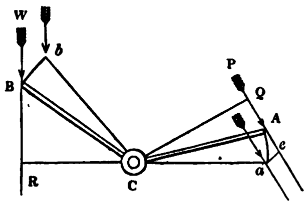


Fig. 16.

Because $\angle$ CAa is a right angle, the $\angle aAe$ is equal to the $\angle$ ACQ and the triangles Aea and ACQ are equiangular,

$$\therefore Aa : CA :: Ae : CQ$$

$$\therefore \frac{Aa}{CA} = \frac{Ae}{CQ} = \frac{\text{velo. P}}{CQ};$$

but $\frac{Aa}{CA}$ is the angular velocity of the rod CA,

$$\therefore \text{ang. velo. CA} = \frac{\text{velo. P}}{CQ} \ldots (1).$$

In like manner, we must have

$$\text{ang. velo. CB} = \frac{\text{velo. W}}{CR}.$$

Now as ACB is rigid, the angular velocity of the arm CA is equal to the angular velocity of the arm CB:—

$$\therefore \frac{\text{velo. P}}{CQ} = \frac{\text{velo. W}}{CR},$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{CQ}{CR} \ldots (2),$$

which is the velocity ratio required. From which it appears, that *the velocities of* P *and* W *are to each other in the ratio of the perpendiculars let fall from the centre of motion upon their respective directions.*

When equilibrium takes place, we have on the principle of *work*, Art. 14.

$$\text{Work on P} = P \times \text{velo. P; work on W} = W \times \text{velo. W};$$

$$\therefore P \times \text{velo. P.} = W \times \text{velo. W};$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{W}{P}.$$

Hence by eq. (2), we have

$$\frac{W}{P} = \frac{CQ}{CR};$$

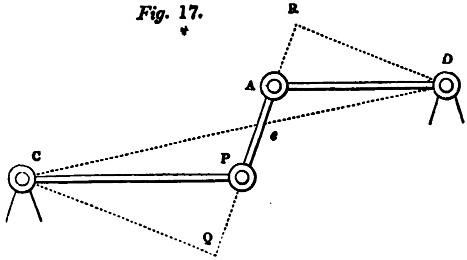
$$\therefore P \times CQ = W \times CR \ldots (3);$$

that is to say, the pressure P multiplied by the perpendicular on its direction is equal to the pressure W multiplied by the perpendicular on its direction. This is the great principle in the *equality of moments.* See the author's "Exercises on Mechanics," page 64.

To find the velocity ratio in a general form of link-work.

31. The link PA connects two rods CP and DA, turning upon their respective fixed centres of motion C and D. From the centres C and D let fall the perpendiculars CQ and DR upon the direction of the link PA produced. Put V for the velocity of the point P or A in the direction

Fig. 17.



PA; then by eq. (1), Art. 30., we have

$$\text{ang. velo. CP} = \frac{V}{CQ}$$

$$\text{ang. velo. DA} = \frac{V}{DR};$$

hence we have by division,

$$\frac{\text{ang. velo. CP}}{\text{ang. velo. DA}} = \frac{DR}{CQ} \dots (1);$$

that is to say, *the angular velocities of the arms* CP, PA *are to each other inversely as the perpendiculars from their centres of motion upon the line of the link.*

Join CD cutting the link in the point e, then the triangles CQe and DRe are equiangular,

$$\therefore \frac{DR}{CQ} = \frac{De}{Ce},$$

hence eq. (1) becomes

$$\frac{\text{ang. velo. CP}}{\text{ang. velo. DA}} = \frac{De}{Ce} \dots (2);$$

that is to say, *the angular velocities of the arms* CP, PA *are to each other inversely as the segments into which the link divides the line joining the centres of the arms.*

When the rod DA becomes parallel to CP, the triangles DAe and CPe are similar, and then

$$\frac{De}{Ce} = \frac{DA}{CP},$$

in this case, therefore, eq. (2) becomes

$$\frac{\text{ang. velo. CP}}{\text{ang. velo. DA}} = \frac{DA}{CP},$$

CHAP. IV.

CORDS, ETC., — PRODUCING MOTION BY WRAPPING CONTACT, — CORD-MOTIONS.

32. If cords were perfectly flexible and could be moved over a surface without friction, they might be used alone for communicating motion in any direction; but as this is not the case, they are employed with wheels, as in the pulley, in transmitting motion.

Pulleys, &c.

33. When a rope PABW passes over a fixed wheel C turning on an axis, the mechanism is called a pulley. A force pulling at the cord PA causes the wheel C to turn upon its axis from the friction of the cord on its edge, and as the wheel turns it gives off cord equal in length to the space described by its circumference.

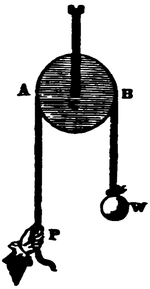


Fig. 18.

Here the motion of P and W must be equal, for whatever space P may descend, W will ascend through the same space. Moreover when equilibrium takes place, the tension or stretch of the single cord PABW must be the same in every part, and the tension of the portion AP will be the same as the tension of the portion BW; therefore the weight P must be equal to the weight W in order to produce these equal tensions.

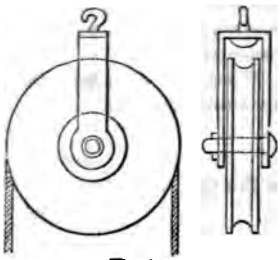


Fig. 19.

A pulley consists of a wheel having a round groove made in its edge or circumference for receiving a cord; this wheel is placed in a frame, and turns on an axis resting between the sides of the frame.

34. The *endless cord* or belt ABCD passes round the wheels AB and DC fixed to the revolving axes EF and KQ, and transmits motion from the axis EF to the axis KQ.

Here the circumferences of the wheels have the same velocity, for the cord which is given off from the wheel DC

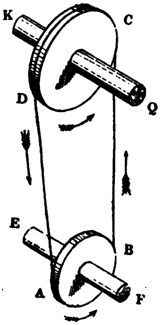


Fig. 20.

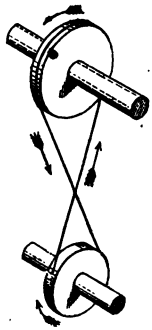


Fig. 21.

passes round the wheel AB; if, therefore, the wheel DC makes 1 revolution, then the number of revolutions made by AB will be the number of times that the circumference of AB can be taken out of the circumference of DC, that is,

$$\text{No. revo. AB} = \frac{\text{circum. DC}}{\text{circum. AB}} \text{ or } \frac{\text{radius DC}}{\text{radius AB}}.$$

If the wheels be equal they will obviously perform the same number of revolutions in the same time.

In *fig.* 20. the cord is said to be *direct*, and the motions of the wheels take place in the *same direction.* In *fig.* 21. the cord is crossed, and the motions of the wheels take place in *opposite directions.*

35. In *fig.* 23. F is a fixed pulley and C a moveable one;

the single or continuous cord PKQABD passes over the wheels F and C and is fixed to a hook D. If W with its pulley C ascend 1 foot the cords BD and AQ will each be shortened 1 foot, and therefore the cord KP will be lengthened 2 feet; that is, the velocity of P will be double the velocity of W.

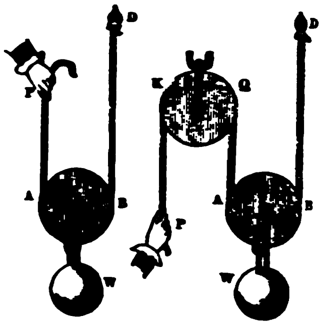


Fig. 22. *Fig.* 23.

When the forces P and W balance each other, we have on the principle of work:—

Work of P=P × 2, Work of W=W × 1,

∴ P × 2 = W × 1,

or W=2P;

that is to say, the power applied will raise twice its weight.

Principle of tension.—The single cord PQBD will have the same tension in every part; now W hangs by the two cords BD and AQ, therefore each cord must sustain a weight equal to one-half W; that is, the cord AQ will have a tension of one-half W; but this tension is resisted by the power at P, therefore P must also be one-half W.

In like manner in *fig.* 22. the velocity of P will be double the velocity of W.

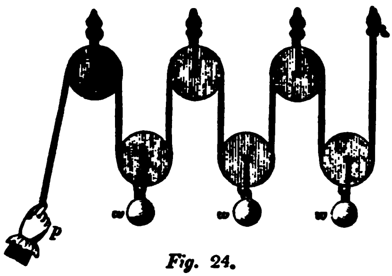


Fig. 24.

36. In this arrangement (see *fig.* 24.) a single cord is doubled three times, but at each duplication the cord given off is equal to twice the space through which the pulley ascends, therefore the velocity of P will be 6 times the velocity of any of the weights *w*.

37. In this system there is also a single cord, and the lower or moveable block is suspended by 6 cords. If W with its block ascend 1 foot, each of these cords will be shortened 1 foot, and therefore the cord P will be lengthened 6 feet; that is to say, the velocity of P will be 6 times the velocity of W.

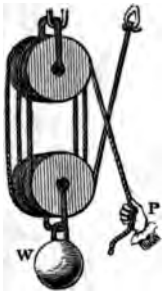


Fig. 25.

Principle of tension. Here a single or continuous cord passes round the wheels, therefore every part of the cord must have the same tension; but W hangs by 6 cords, therefore each cord will carry one-sixth of the weight W, and consequently the power P must also be one-sixth of W. If W be 12lbs., each cord will support one-sixth of 12lbs. or 2lbs., therefore P must be 2lbs.

38. In the system of pulleys represented in *fig.* 26. there are three distinct cords and three moveable pulleys, making three duplications of cord; therefore supposing W, with its pulley, to ascend 1 foot, the velocity of each successive pulley will be double that of its preceding one, and also the velocity of the power P will be double that of the last pulley; that is in this case, P will descend 8 feet, or

$$\text{velo. P} = \text{velo. W} \times 2 \times 2 \times 2 = 2^3 \times \text{velo. W};$$

generally if there are *n* moveable pulleys, then

$$\text{velo. P} = 2^n \times \text{velo. W}.$$

Principle of tension. Let W be 8lbs., then the cords P_2 and C will each have a tension of 4lbs.; as the cord P_2 has a tension of 4lbs., the cords P_1 and B will each have a tension of 2lbs.; as the cord P_1 has a tension of 2lbs. the

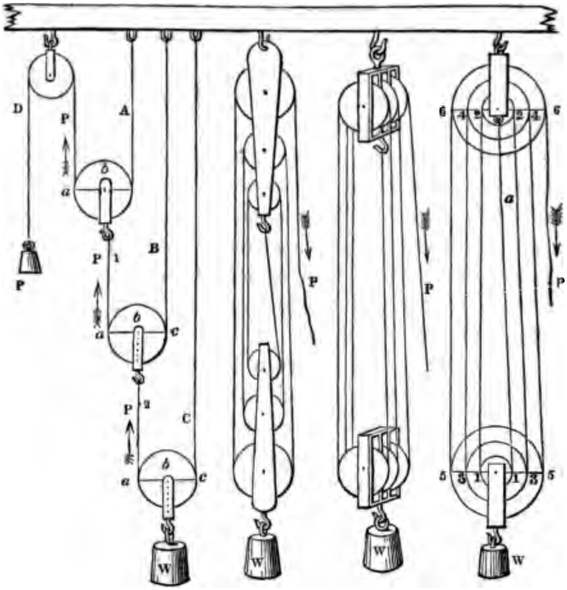


Fig. 26. *Fig.* 27. *Fig.* 28. *Fig.* 29.

cords P and A will each have a tension of 1 lb.; but the cord D has the same tension as the cord P, therefore the power P must be 1 lb., that is a power of 1 lb. will sustain a weight of 8 lbs.

39. The system of pulleys represented in *figs.* 27 and 28. is the same in principle as that of *fig.* 25.

40. In the system *fig.* 29., with the view of reducing the friction, the wheels in each block are cut out of a solid piece of timber, and consequently turn upon the same centre. In order to suit this arrangement the wheels must have different sizes corresponding to the velocities of their respective cords.

Let W and its block ascend 1 foot, then the cords 1*a* and 12 will each be shortened 1 foot, and therefore 1 foot of

pass over the wheel 1 1, while 2 feet must pass
vheel 2 2; now these 2 feet of cord move in the
? 3, but the wheel 3 3 rises 1 foot, therefore 3 feet
ıst pass over the wheel 3 3; these 3 feet of cord
he direction 3 4, but the cord 3 4 is at the same
ened 1 foot by the ascent of the lower block, there-
t of cord must pass over the wheel 4 4; these
cord move in the direction 4 5, but the wheel 5 5
t, therefore 5 feet of cord must pass over the wheel
5 feet of cord move in the direction 5 6, but the
at the same time shortened 1 foot by the ascent of
block, therefore 6 feet of cord must pass over the
; and these 6 feet of cord move in the direc-

ng these results, it appears that the wheel 1 1
off 1 foot of rope; 2 2 must turn off 2 feet;
turn off 3 feet; 4 4 must turn off 4 feet; 5 5 must
feet; and 6 6 must turn off 6 feet. Now as the
each block, having the same axis, perform a revo-
he same time, it follows that their circumferences
each other as the lengths of cord
ey have respectively to turn off;
the circumferences, or diameters of
in the upper block must be as the
bers 6, 4, and 2; and those in the
k as the odd numbers 5, 3, and 1.

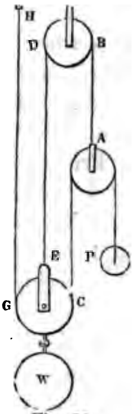


Fig. 30.

two systems of pulleys, represented
and 31., are called *Spanish Bartons.*
ystem there are two moveable pul-
ixed pulley, and two single cords.
30. let W, with its pulley CG, ascend
n 2 feet of cord must pass from the
; but at the same time the cord ED
ed 1 foot, therefore the pulley A
end 1 foot, and from *this cause* 2 feet
ıst pass from the pulley A; but 2 feet of cord also

pass from the pulley GC, therefore 4 feet of cord must pass from the pulley A, that is, P must descend 4 feet. Hence the velocity ratio of P to W is as 4 to 1.

Principle of tension. Let P=1 lb., then the cord PACGH being a single cord, the cords PA, AC, and GH, will each have a tension of 1 lb.; but the cord AB has a tension of 2 lbs., for it sustains the tensions of AP and AC; now ABDE being a single cord, the cord ED has the same tension as the cord AB; that is, ED must sustain a tension of 2 lbs., but the cords GH and AC have each a tension of 1 lb.; therefore W must be 4 lbs., in order to produce the tensions of GH, ED, and CA. Hence if P be 1 lb. W must be 4 lbs.

42. In *fig.* 31. let W, with its pulley CD, ascend 1 foot, then the cord IF will be shortened 1 foot, and therefore the pulley B with the cord ED must descend 1 foot; but the pulley CD ascends 1 foot, therefore 3 feet of cord must pass from the wheel CD; these 3 feet move in the direction CG, but the pulley B descends 1 foot, which causes 2 feet more to pass from the wheel B; that is, 5 feet must pass from the wheel B, and the power P must descend 5 feet. Hence the velocity ratio of P to W is as 5 to 1.

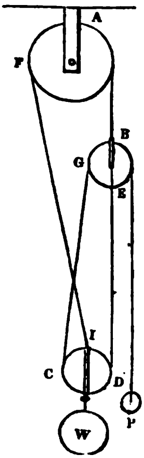


Fig. 31.

Principle of tension. Let P=1 lb., then PBGCDE being a single cord, the cords PB, GC, and DE will each have a tension of 1 lb.; but the cord BA has a tension of 3 lbs., for it sustains the tensions of PB, GC, and DE; now BAFI being a single cord, the tension of the cord IF has the same tension as the cord BA; that is, IF must sustain a tension of 3 lbs.; but the cords CG and DE have each a tension of 1 lb., therefore W must be 5 lbs., in order to produce the tensions of IF, CG, and DE. Hence if P be 1 lb. W must be 5 lbs.

Guide Pulleys.

43. The direction of motion in cords may be changed into *any* other direction by the intervention of *Guide Pulleys.* Thus *e* and *g* are guide pulleys changing the motion of the cord *d c* into *any* other direction *g a.* The cords *d c* and *e g* should be in the plane of the pulley *e*; and the plane of the pulley *g* should be in the plane of the cords *e g* and *g a.* If the directions of the cords *d c* and *g a* are in the same plane, one guide pulley would serve the purpose.

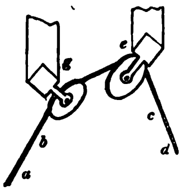


Fig. 32.

44. Two guide pulleys D and E may be employed to transfer motion from the wheel A to the wheel B, whose axes have any given direction.

Let DE be the line where the planes of the two wheels, A and B, intersect. In this line assume any two convenient points, D and E; and in the plane of the wheel A, draw the tangents DC and EH; and in like manner, in the plane of the wheel B, draw the tangents DG and EF; then CDGFEH will be the path of an endless cord, which may be kept in this path by a guide pulley at D in the plane of CDG, and another one at E in the plane of HEF.

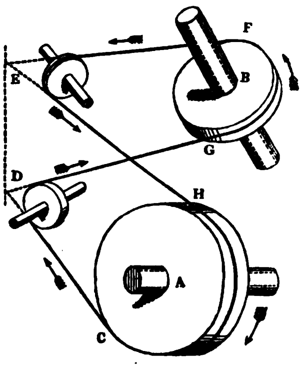


Fig. 33.

Forms of Wrapping Connectors.

45. If a tight belt run on a conical wheel which revolves

on its axis, the belt will gradually advance towards the broad side of the wheel, owing to the belt being more stretched on that side than on the other. This curious property is used in the construction of wheels to which motion is given by belts. Thus in order that a belt may not shift along the edge of a wheel, this edge is made to swell a little in the middle, as in the annexed figure.

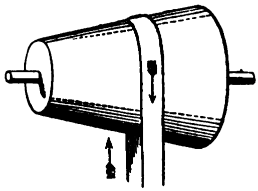


Fig. 34.

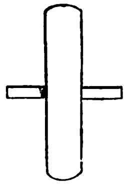


Fig. 35.

46. When a wheel presents considerable resistance to motion, belts and cords are liable to slide upon the wheel; in such cases *geering chains* of a variety of forms have been used.

Fig. 36. shows a geering chain where the links lay hold of the teeth formed on the wheel.

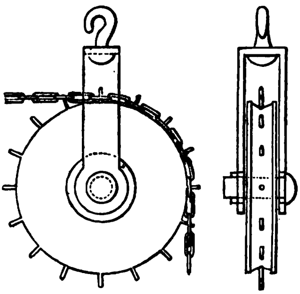


Fig. 36.

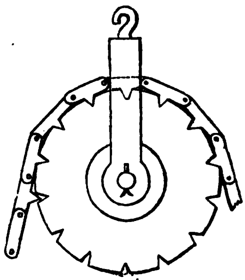


Fig. 37.

Fig. 37. shows another form of geering chain, where the links (jointed together something like a watch chain) carry teeth, which pass into notches made on the edge of the wheel.

47. When two wheels or rollers have to make only a limited number of revolutions in each direction, the slipping of the cord may be completely prevented by having a cord coiling round each end of the rollers, as in *fig.* 38. While the cord is being coiled on the extremity *d* of the roller A, it is uncoiled from the extremity *c* of the roller B; and at the same time, while the cord is uncoiled from the extremity *a* of the roller A, it is coiled on the extremity *b* of the roller B.

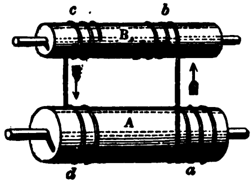


Fig. 38.

Wheel and Axle, with Cord Connectors.

48. The common wheel and axle consists of a horizontal axle A and large wheel R, which turn upon two pivots supported in gudgeons. A cord wrapping round the axle A sustains the weight W, and another cord wrapping round the wheel R, in contrary direction, sustains the power P.

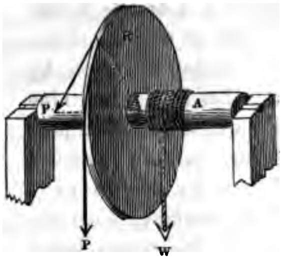


Fig. 39.

Let the wheel with the axle make one revolution in the direction of the arrow P, then one coil of cord will be thrown off the wheel R, while one coil will be wrapped upon the axle A; therefore P will descend a space equal to the circumference of the wheel R, while W will ascend a space equal to the circumference of the axle; that is, the velocity of P will be as many times the velocity of W as the circumference of R is that of the circumference of A; or we have

$$\frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{circum. wheel R}}{\text{circum. axle A}} \text{ or } \frac{\text{radius R}}{\text{radius A}} \ldots (1).$$

If the circumference of the wheel R be double that of the axle, then the velocity of P will be double the velocity of W.

For the condition of equilibrium, we have on the principle of work,

$$\text{P} \times \text{velo. P} = \text{W} \times \text{velo. W},$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{W}}{\text{P}}, \text{ therefore by eq. (1),}$$

$$\frac{\text{W}}{\text{P}} = \frac{\text{radius wheel R}}{\text{radius axle A}},$$

$$\text{or P} \times \text{radius wheel} = \text{W} \times \text{radius axle} \dots (2).$$

If the radius of the axle be 2 inches, and the radius of the wheel 14 inches, then the weight raised will be 7 times the power applied; thus

$$\frac{\text{W}}{\text{P}} = \frac{\text{radius wheel}}{\text{radius axle}} = \frac{14}{2} = 7.$$

49. If instead of the wheel R, a handle is employed, to which a circular motion is given by the hand, the machine is called a Windlass. Thus, in the annexed figure, CE is the axle, W the weight; CBD the handle, the power being applied at D. Here the length of the handle CD is the radius of the circle described by the power.

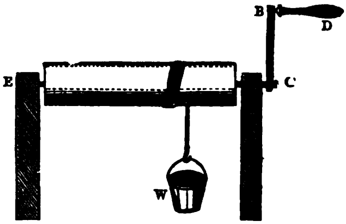


Fig. 40.

50. When the axle is placed in a vertical position, and the power is applied by means of bars or levers inserted into the holes at H, the machine is called a *Capstan*. In this case the cable coils round the axle in the form of an endless rope, which winds round the lower part of the axle, and at the same time unwinds from the up-

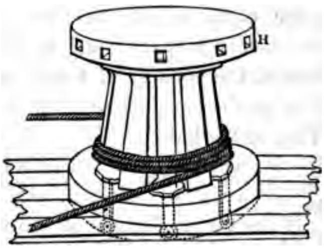


Fig. 41.

per. The axle is made conical, to enable the workman to shift the cable upwards, as it becomes necessary.

51. *In the compound wheel and axle*, the axle is made of different thicknesses as at A and D, and a cord coils round these parts in different directions. This cord passes round a moveable pulley BC, from which the weight W is suspended.

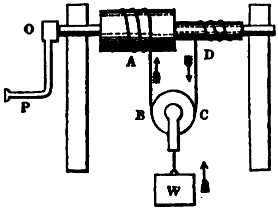


Fig. 42.

In one turn of the handle P, the cord AB is coiled up once round the large axle A, while the cord DC is uncoiled once from the small axle D, therefore the cord DCBA is shortened by a space equal to the difference of the circumferences of A and D, and the weight W must rise a space equal to half this difference; that is,

The space moved over by W *is equal to half the difference of the circumferences of* A *and* D.

And the space moved over by P *is equal to the circumference of the circle described by* P.

But these spaces are described in the same time, therefore they may be respectively taken to represent the velocities of W and P.

Ex. Let the diameter of A=6 in., diameter of D=4 in., and length of the handle PO=20 in.

Here we have

Space moved over by P$=2\times 20\times 3{\cdot}1416=40\times 3{\cdot}1416$.

Circum. A$=6\times 3{\cdot}1416$; circum. D$=4\times 3{\cdot}1416$;

$\therefore$ space the cord DCBA is shortened$=6\times 3{\cdot}1416-4\times 3{\cdot}1416$
$=2\times 3{\cdot}1416$;

$\therefore$ space moved over by W$=\frac{1}{2}$ of $2\times 3{\cdot}1416=3{\cdot}1416$;

but the space moved over by P is 40 times this quantity; therefore the velocity of P will be 40 times the velocity of W.

Now by the principle of work, Art. 14., the velocity of P is as many times the velocity of W as the weight of W is that of P; therefore in this case W must be 40 times P; that is, the pressure applied at the handle will be increased 40 times in this machine.

Generally let l = the length of the handle PO, R = the radius of A, r = the radius of D, and $\pi = 3 \cdot 1416$; then, in one revolution,

$$\text{Space moved over by P} = 2\pi l.$$

$$\text{Circum. A} = 2\pi R; \text{ circum. D} = 2\pi r;$$

$$\therefore \text{ Space the cord DCBA is shortened} = 2\pi R - 2\pi r = 2\pi(R - r),$$

$$\therefore \text{ Space moved over by W} = \tfrac{1}{2} \text{ of } 2\pi(R - r) = \pi(R - r).$$

Comparing this equality with the first, we have

$$\frac{\text{space moved over by P}}{\text{space moved over by W}} = \frac{2\pi l}{\pi(R - r)} = \frac{2l}{R - r};$$

$$\text{that is, } \frac{\text{velo. P}}{\text{velo. W}} = \frac{2l}{R - r} \dots (1),$$

which is the velocity ratio of P to W.

Now on the principle of work, Art. 14., this velocity ratio is equal to $\frac{W}{P}$,

$$\therefore \frac{W}{P} = \frac{2l}{R - r} \dots (2).$$

In the example above given, $l = 20$, $R = 3$, and $r = 2$,

$$\therefore \frac{W}{P} = \frac{2 \times 20}{3 - 2} = 40, \text{ as before.}$$

52. In this figure F represents a wheel with its axle BC turning on a common axis, and AD another wheel, with its axle E. The power P is suspended by a cord which wraps round the wheel F; and the weight W is suspended by a cord which wraps round the axle E. Motion is transmitted from P to

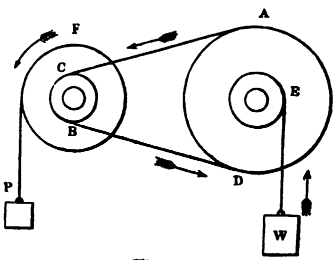


Fig. 43.

W by means of a cord or strap passing round the axle BC and wheel AD.

Let the wheel AD, with its axle E, make one revolution, then the cord EW will be coiled up once round the axle E, and the number of revolutions made by the axle BC, with its wheel F, will be equal to the number of times that the circumference of BC is contained in the circumference of AD; and moreover the cord FP will be uncoiled from the wheel F as many times as it makes revolutions.

Ex. Let the diameter of F=36 in., diameter CB=4 in., diameter AD=48 in., and the diameter E=3 in.

Let the wheel AD make 1 revolution, then

Space moved over by W=circum. E$=3\times 3{\cdot}1416$.

Circum. AD$=48\times 3{\cdot}1416$; circum. BC$=4\times 3{\cdot}1416$;

$$\therefore \text{No. revo. BC or wheel F}=\frac{48\times 3{\cdot}1416}{4\times 3{\cdot}1416}=12.$$

Cord given off from F in 1 revo.$=36\times 3{\cdot}1416$

∴ „ „ „ F in 12 revo.$=12\times 36\times 3{\cdot}1416$.

That is, space moved over by P$=12\times 36\times 3{\cdot}1416$;

but the space moved over by W in the same time is $3\times 3{\cdot}1416$;

$$\therefore \frac{\text{velo. P}}{\text{velo. W}}=\frac{12\times 36\times 3{\cdot}1416}{3\times 3{\cdot}1416}=144;$$

that is, the velocity of P is 48 times that of W.

And by the principle of work, Art. **14.**, W must be 144 times P when equilibrium takes place.

Or generally, let D=the diameter of F, d=the diameter of BC, D_1= the diameter of AD, and d_1=the diameter of E. Let the wheel AD make 1 revolution, then

Space moved over by W=circum. E$=\pi d_1$.

Circum. AD$=\pi D_1$, Circum. BC$=\pi d$,

$$\therefore \text{No. revo. BC or wheel F}=\frac{\pi D_1}{\pi d}=\frac{D_1}{d}.$$

$$\text{Cord given off from P in 1 revo.} = \pi D,$$

$$\therefore \quad ,, \quad ,, \quad ,, \quad \text{in } \frac{D_1}{d} \text{ revo.} = \frac{D_1}{d} \text{ times } \pi D,$$

$$\text{that is, space moved over by P} = \frac{D_1}{d} \text{ times } \pi D = \frac{\pi D D_1}{d},$$

comparing this with the first equality, we have

$$\frac{\text{space moved over by P}}{\text{space moved over by W}} = \frac{\pi D D_1}{d} \div \pi d_1 = \frac{D D_1}{d d_1},$$

$$\text{that is, } \frac{\text{velo. P}}{\text{velo. W}} = \frac{D D_1}{d d_1} \; \dots (1),$$

which is the velocity ratio of P and W; where *the product of the diameter of the wheels is divided by the product of the diameters of the axles.*

In the example above given, $D = 36$, $d = 4$, $D_1 = 48$, and $d_1 = 3$,

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{36 \times 48}{4 \times 3} = 144, \text{ as before.}$$

Also on the principle of work, see Art. 14,

$$\frac{W}{P} = \frac{D D_1}{d d_1} \; \dots (2).$$

Speed Pulleys.

53. Let AB and CD be two parallel axes upon each of which is fixed a series of pulleys of different diameters, and adapted for belts. By shifting the belt from one pair of pulleys to another, a change in the velocity ratio of the two axes is produced: thus, if the belt passes over the first pair at B and D, the axis AB will have a slower motion than that of CD, and so on to other cases. Such arrangements are called *speed pulleys.* In order that the same cross belt may exactly fit every pair of pulleys, they are cut out of two equal cones and placed in the manner shown in the figure.

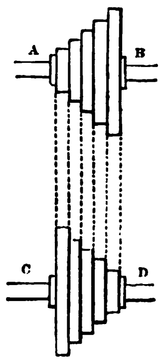


Fig. 44.

The two equal plain cones, shown in *fig.* 45., will obviously answer the same purpose.

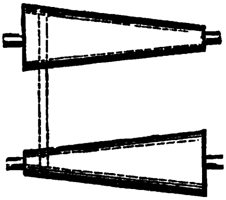


Fig. 45.

The Fusee of a Watch.

54. A is a plain cylinder or drum, turning on the axis AD; B is a solid truncated pulley or fusee, on whose surface a spiral channel is cut; A and B turn upon axes parallel to each other; *a c d b* is a cord or chain, which goes about the drum A, winds round the spiral of the fusee, and has its extremity fixed at the apex *b*. Now if A be turned uniformly round, the fusee B, by means of the chain, will be turned round in the same direction, but with a variable velocity; this velocity will be proportional to the distance of the cord from the axis.

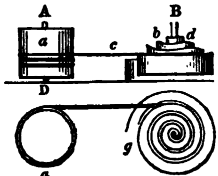


Fig. 46.

In a common watch, a spring is enclosed in the hollow cylinder *a*, to give it a rotatory motion; and in order to equalise the varying force of the spring, as it uncoils itself, the chain is made to act with an increasing leverage on the fusee.

To produce a variable Velocity.

55. *Fig.* 47. represents a contrivance for giving a varying velocity to the axis D, by means of an endless band QRB. Here C is the axis of a driving pulley, whose edge is curved in such a manner as may be required to produce the varying velocity; D R is a circular pulley fixed on the axis D; in order to keep the band constantly stretched, it passes over a *stretching pulley* B, having a

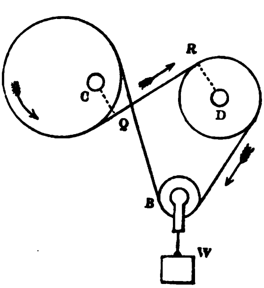


Fig. 47.

weight W suspended from it. Suppose the axis O to revolve uniformly, then, owing to the eccentricity of the pulley C, a varying length of cord will be passed off, and therefore a varying motion will be produced in the pulley D. Let CQ and DR be perpendiculars on the cord QR, then, by Art. 56.,

$$\frac{\text{ang. velo. C}}{\text{ang. velo. D}} = \frac{\text{DR}}{\text{CQ}}.$$

To find the ratio of the angular velocities of two eccentric wheels, moved by a cord wrapping over each.

56. Let PA be a cord wrapping round the two wheels whose centres of motion are C and D; then the line PA will form a tangent to the two curves forming the edges of the wheels. On PA produced let fall the perpendiculars CQ and DR; then the velocity of the cord PA will be equal to the velocity of the point Q, and at the same time also equal to the velocity of the point R;

$$\therefore \text{velo. Q} = \text{velo. R},$$

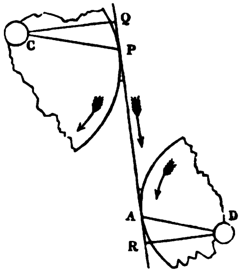


Fig. 48

each being estimated in the direction PA;

but

$$\text{velo. Q} = \text{ang. velo. CQ} \times \text{CQ}$$
$$= \text{ang. velo. CP} \times \text{CQ},$$
$$\text{and velo. R} = \text{ang. velo. DR} \times \text{DR}$$
$$= \text{ang. velo. DA} \times \text{DR},$$
$$\therefore \text{ang. velo. CP} \times \text{CQ} = \text{ang. velo. DA} \times \text{DR};$$
$$\therefore \frac{\text{ang. velo. CP}}{\text{ang. velo. DA}} = \frac{\text{DR}}{\text{CQ}};$$

that is to say, *the angular velocities are inversely as the perpendiculars let fall upon the cord, from the centres of motion.*

To find the velocities of the weights P *and* W *attached to pulleys when the connecting cords are not all parallel to each other.*

57. Let A be a moveable pulley, with its weight W, suspended from the cord PCAB, passing over a fixed pulley, and attached to a hook B in the same horizontal line with C. From A let fall AK perpendicular to CB; then it is obvious, that AB must be equal to AC, and that A must move in the vertical line AK. Let A move from A to *r*; with C*r* and B*r* as radii, and on C and B as centres, describe the arcs *ra* and *rn*;

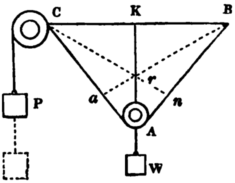


Fig. 49.

then the cords AC and AB will be respectively shortened by Aa and An;

$$\therefore \text{ space descended by } P = Aa + An = 2Aa;$$

but space ascended by $W = Ar$;

$$\therefore \text{ velo. } P : \text{velo. } W :: 2Aa : Ar$$

$$\therefore \frac{\text{velo. } P}{\text{velo. } W} = \frac{2Aa}{Ar}.$$

Now when the motion Ar is indefinitely small, the arc ar becomes a straight line perpendicular to AC, therefore the triangles Aar and AKC are similar, and

$$\therefore \frac{Aa}{Ar} = \frac{AK}{AC},$$

$$\therefore \frac{\text{velo. } P}{\text{velo. } W} = 2 \times \frac{AK}{AC} \ldots (1).$$

This expression may be put into a trigonometrical form, for we have

$$\frac{AK}{AC} = \cos. CAK \text{ or } \cos. PCA.$$

hence eq. (1) becomes

$$\frac{\text{velo. } P}{\text{velo. } W} = 2 \times \cos. PCA \ldots (2).$$

On the principle of work, we have

$$P \times \text{velo. } P = W \times \text{velo. } W,$$

$$\therefore \frac{\text{velo. } P}{\text{velo. } W} = \frac{W}{P},$$

therefore by eq. (2)

$$\frac{W}{P} = P \times 2 \cos. PCA,$$

$$\text{or } W = P \times 2 \cos. PCA \ldots (3),$$

which is the equation of equilibrium.

CHAP. V.

WHEEL-WORK, PRODUCING BY ROLLING CONTACT — WHEEL-MOTIONS.

58. This figure shows two wheels or cylinders, A and B, in contact with each other, and revolving upon their re-

spective axes EF and CD, which are parallel to each other. Now if the wheels are in contact in any one position they will obviously be in contact in any other position; hence they will roll upon each other, and if B revolve on its axis EF, it will communicate a rotary motion to the wheel A, in a contrary direction, by the friction or adhesion of the parts successively brought in contact. The edges of these wheels will obviously have the same velocity.

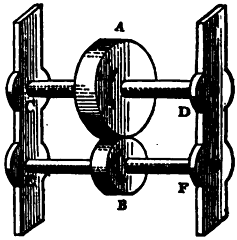


Fig. 50.

If the radius of A be 3 times that of B, then the circumference of A will also be 3 times the circumference of B; therefore for every revolution which A makes, B will make 3. Or generally, as many times as the circum. of B can be taken out of the circum. of A, or what is the same thing, as many times as the radius of B can be taken out of the radius of A, so many times will B revolve, while A makes one revolution.

59. Owing to the practical difficulty of making wheels exactly to roll on each other, it is customary to form the edges of the wheels into *teeth*, which must be placed at equal distances from each other on the edges of the wheels, so that when one wheel is turned, its teeth shall successively enter into the spaces formed on the edge of the other wheel. When a tooth is about to quit its corresponding space, the next tooth in succession enters the next space, and so on continually; thus the one wheel cannot escape from the other, which may happen in the case of simple rollers, even should there be some slight error in the construction.

Spur Wheels.

60. If the toothed wheel B drive the toothed wheel A, then B is called *the driver* and A *the follower*. Wheels acting in this manner are also called *Spur wheels.*

Small toothed wheels are called *pinions;* thus B may be called a pinion in relation to A. Two toothed wheels are said to be *in gear* when their teeth are engaged together, and out of gear when they are separated.

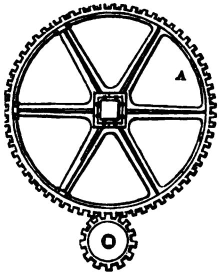


Fig. 51.

If B contain 15 teeth and A 90, then B must turn round 6 times in order that A may turn round once. Or, generally, if A make one revolution, the number that B will make is found by dividing the number of teeth in A by the number in B. Or since the number of teeth in the wheels are proportional to their radii, the number of revolutions of B will also be found by dividing the radius of A by the radius of B; thus let the radius of A be 15 in., and that of B 3 in.; then B will make 5 revolutions while A makes one.

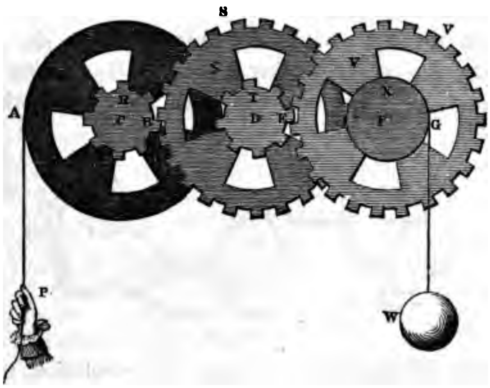


Fig. 52.

61. To find the velocity ratio of P and W in the system of wheels shown in *fig.* 52. Let the diameter of the axle G=4 in.; number of teeth in the wheel V=32; number of teeth in the pinion T=8; in the wheel S=21; in the pinion R=7; and the diameter of the wheel A=24 in.

Suppose the pinion G, with its wheel V, to make 1 revolution, then

$$\text{Space moved over by W}=4\times 3\cdot 1416.$$

$$\text{No. revo. of T or S}=\frac{\text{no. teeth in V}}{\text{no. teeth in T}}=\frac{32}{8}=4.$$

$$\text{No. revo. of R or A, when S makes } 1=\frac{21}{7}=3,$$

$$\therefore \quad ,, \quad ,, \quad ,, \quad ,, \quad \text{when S makes } 4=4 \text{ times } 3=12;$$

that is the wheel A makes 12 revolutions;

$$\therefore \text{ space passed over by P}=\text{circum. A}\times 12$$
$$=24\times 12\times 3\cdot 1416=288\times 3\cdot 1416.$$

Therefore the velocity of P is to the velocity of W as $288\times 3\cdot 1416$ is to $4\times 3\cdot 1416$, that is, the velocity of P will be 72 times the velocity of W. And on the principle of work, the weight of W will be 72 times that of P, when equilibrium takes place.

62. In the train of wheels represented in *fig.* 53., let N_1, N_2, N_3, &c. be the number of teeth in the *driving* wheels, and n_1, n_2, n_3, &c. the number in the *driven* wheels or *followers.*

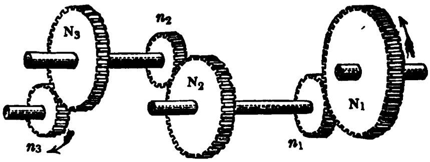


Fig. 53.

Let the driving wheel N_1 make one revolution, then the follower n_1 will make $\frac{N_1}{n_1}$ revolutions; while N_2 makes one revolution n_2 will make $\frac{N_2}{n_2}$ revolutions, but n_2 makes $\frac{N_1}{n_1}$ revolutions, therefore n_2 will make $\frac{N_1}{n_1}\times\frac{N_2}{n_2}$ revolutions; and so on, so that while N_1 makes one revolution, we have

$$\text{No. revo. of } n_3 = \frac{N_1}{n_1} \times \frac{N_2}{n_2} \times \frac{N_3}{n_3} = \frac{N_1 \times N_2 \times N_3}{n_1 \times n_2 \times n_3},$$

that is generally, ***the number of revolutions of the last follower in the train will be equal to the product of the number of teeth in the driving wheels divided by the product of the number of teeth in the followers.***

Annular Wheels.

63. When one wheel transmits motion to another, as in *fig.* 51., where the teeth are cut on the external edges, the wheels revolve in contrary directions ; now in the annular wheels, represented in *fig.* 54., the large wheel A has its teeth cut on the internal edge of the annulus or rim, which causes it to revolve in the same direction as the pinion B.

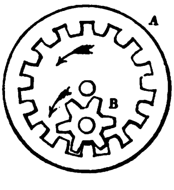


Fig. 54

Idle Wheels.

64. The wheel *b* placed between two other wheels *a* and *c*, does not affect the velocity ratio of these wheels, for *c* would obviously move with the same speed that it would have were its teeth immediately engaged with *a*. But the intermediate wheel *b* causes *a* and *c* to revolve in the *same direction*, whereas if *a* and *c* were in contact they would revolve in *opposite directions*. The intermediate wheel *b* is called an *idle wheel.*

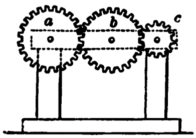


Fig. 55.

Teeth of Wheels. Pitch Circles, &c.

65. The teeth of wheels should have a curved shape, in order that the motion communicated from one wheel to another may be regular and smooth, or in other words, that there may be a perfect rolling contact between them. When teeth are angular, as in the last figure, they slip over each other, in certain positions, and this is attended with considerable friction and a want of uniformity in the rotation of the wheels.

The annexed figure shows the curved form which is usually given to the teeth of wheels. The circles E E and F F, touching each other at A, and described from the respective centres of the two wheels, are called PITCH CIRCLES. The radii of these pitch circles are always taken proportional to the number of teeth in their respective wheels; thus if the upper wheel has 9 teeth and the lower one 36, then the radius of the pitch circle E E will be to the radius of the pitch circle F F as 9 is to 36, or as 1 is to 4. Hence the pitch circles would roll upon each other and complete their rotations in the same manner as the wheels would do after their teeth are formed.*

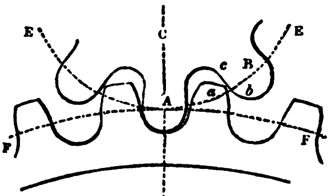


Fig. 56.

Let the circumference of the pitch circle be divided into the same number of equal parts as there are teeth in the wheel, then the length of one of these parts will be the distance occupied by a tooth and a space; this distance is called the *pitch of the teeth*. In cast-iron wheels, it is customary to make the pitch of the teeth of the following values,—1 in., $1\frac{1}{8}$ in., $1\frac{1}{4}$ in., 2 in., $2\frac{1}{2}$ in., and 3 in.

Ex. 1. A driving wheel is to have 5 teeth, and the follower 40; it is required to find the diameters of the *pitch circles*, when the *pitch of the teeth* is 2 in.

$$\text{Circum. driver} = 5 \times 2 = 10 \text{ in.}$$

$$\therefore \text{ diam. driver } = \frac{10}{3{\cdot}1416} = 3{\cdot}183 \text{ in.}$$

* On the form of teeth see "Moseley's Engineering," or "Willis's Mechanism."

In like manner,

$$\text{Diam. follower}=\frac{40 \times 2}{3{\cdot}1416}=25{\cdot}464 \text{ in.}$$

Ex. 2. The diameter of the pitch circle is 48 in., and the pitch of the teeth $2\frac{1}{2}$ in., required the number of teeth in the wheel.

$$\text{Circum. pitch circle}=48 \times 3{\cdot}1416,$$

$$\therefore \text{ no. teeth}=\frac{\text{circum. pitch circle}}{\text{pitch of teeth}}=\frac{48 \times 3{\cdot}1416}{2{\cdot}5}=60.$$

Ex. 3. The diameter of a pitch circle is 30 in., and the number of teeth 94; required the pitch of the teeth.

$$\text{Circum. pitch circle}=30 \times 3{\cdot}1416,$$

$$\therefore \text{ pitch of teeth}=\frac{\text{circum. pitch circle}}{\text{number of teeth}}=\frac{30 \times 3{\cdot}1416}{94}=1 \text{ in.}$$

Generally, let d=the diameter of the pitch circle, n=the number of teeth, and p=the pitch of the teeth, then

$$\text{circum. pitch circle}=d \times 3{\cdot}1416;$$

but we have also,

$$\text{circum. pitch circle}=n\,p$$

$$\therefore d \times 3{\cdot}1416=n\,p,$$

where we have three quantities, any two of which being given the remaining one may be found; thus,

$$d=\frac{n\,p}{3{\cdot}1416}.$$

Let n=40, and p=2, as in Ex. 1.; then

$$d=\frac{40 \times 2}{3{\cdot}1416}=25{\cdot}46, \text{ as before.}$$

FORMS OF WHEEL WORK WHEN THE AXES ARE NOT PARALLEL.

When motion is communicated from one axis to another one, which is parallel to it, *spur wheels* are usually employed, such as are shown in the figures to Art. 60.; but if the motion is to be transferred from one axis to another one at right angles to it, crown-wheels, face-wheels, or bevelled wheels, must be employed.

Crown Wheels.

66. This figure represents a *crown wheel* B, with its pinion A, having their axes at right angles to each other. The teeth in the crown wheel are cut on the edge of a hoop, and the pinion is made thicker than usual. This kind of wheel is used in clock and watch work.

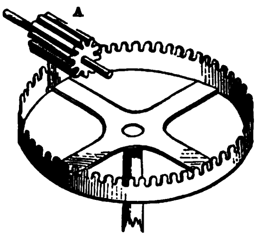


Fig. 57.

Face Wheel and Lantern.

67. In this figure F represents a *face wheel*, with its *lantern* L. Motion is here transferred from a vertical axis to a horizontal one. The teeth inserted into the face of the wheel F, are called *cogs*, which are now usually made of iron, while the round *staves* forming the teeth of the lantern are made of hard wood; for it has been ascertained that iron cogs work with less noise and friction upon wooden staves, than when the cogs and staves are made of the same material. The face wheel and lantern have been much used in mill work.

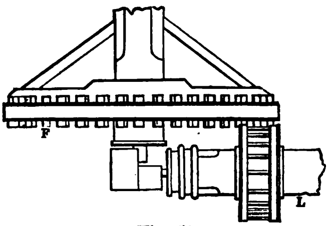


Fig. 58.

Bevel Wheels, or Bevel Gear.

68. Let EB and FB be two axes of rotation cutting each other in B. Two right cones ABC and BDC, touching each other in the line BGC, are formed upon these axes.

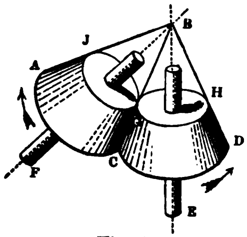


Fig. 59.

If the cone BDC revolve on its axis EB, it will communicate, by rolling contact, a rotatory motion to the cone ABC, upon its axis FB.

In practice frusta of the cones are employed, as ACGJ, and CDHG.

These cones, or frusta of cones, will obviously perform their revolutions in the same manner as the spur wheels in Art. 58.

On these smooth surfaces of the frusta, a series of equidistant teeth may be cut, directed to the apex B of the cone, so that a line passing from the apex B to the outline of the teeth upon the bases of the cones shall touch the teeth in every part, as shown in the annexed cut; where B is the apex of the cones BAC, and BDC, F and E the two axes of the *bevel wheels* AC and DC, intersecting in the apex B.

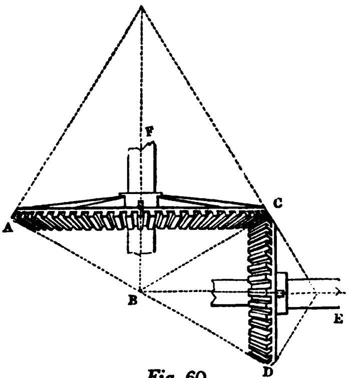


Fig. 60.

Wheels cut in this manner are called *bevel gear.* Two bevel wheels of this kind will always communicate motion from one axis to another, provided these axes intersect each other; this point of intersection is always made the apex of the frusta forming the bevel wheels.

69. Given the radii of two bevelled wheels, and the position of their axes, to construct the cones, or rather the frusta forming the wheels.

Let AB and CD be the position of the axes intersecting each other in O. Draw *a b* parallel to A B, at a distance from A B equal to the radius of the wheel on the axis OB; and draw *d c* parallel to CD, at a distance from CD equal to the radius of the wheel on the axis OD. Let *a b* and *d c* intersect each other in the point *i*; from *i* draw *i m* and *i n* respectively perpendicular to the axes OB and OD; take *i m* equal to the diameter of the wheel on the axis OB, and *i n* equal to the diameter of the wheel on the axis OD; join O*m*, O*i*, and O*n*, then O*mi* and O*in* will be the cones, and O*i* their line of contact.

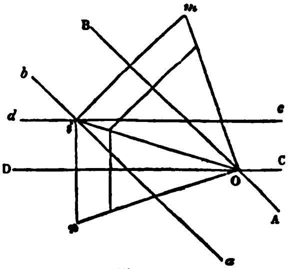


Fig. 61.

Intermediate Bevel Wheels.

70. Here the intermediate bevel wheels B and C revolving on the same axis, connect the driving wheel A with the two wheels E and D. Now the wheel D will revolve in the same direction as A; whereas the wheel E will revolve in a direction contrary to A.

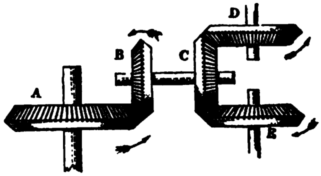


Fig. 62.

71. Given the position of two axes which do not intersect each other, to construct bevelled wheels which shall communicate motion from the one to the other.

Let AB and EF be the two axes, take OE as a third axis, intersecting the axis A B and EF at any convenient points, O and E respectively. Now O will be the vertex of two rolling cones, or rather two frusta a and e; and E will be the vertex of two other rolling cones, or rather frusta, c and d: thus the intermediate axis C D, with its bevelled teeth on c and e, will transmit motion from the axis E F to the axis A B.

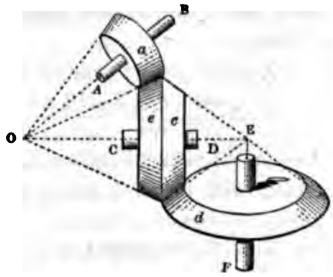


Fig. 63.

It is evident that the bevelled wheel a will have exactly the same rotatory velocity as if it were in immediate contact with the bevelled wheel d.

Rack and Pinion.

72. When a circular motion is to be changed into a rectilinear one, the teeth are cut upon the edge of a straight bar A B, so that they may work with the teeth upon the wheel or pinion P. The toothed bar A B is called a *rack*, and is constrained to move in its rectilinear path by guides or rollers.

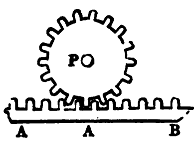


Fig. 64.

73. This figure shows the manner in which power is applied to move a rack; where R is a handle giving a circular motion to the pinion r, which as it turns gives a vertical motion to the rack S.

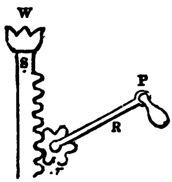


Fig. 65.

Ex. Let the length of the handle R be 18 in. and let the distance between the teeth of the rack or the pinion be $\frac{1}{2}$ in.; required the velocity ratio of the handle and rack, when the pinion has 6 teeth.

Let the handle make 1 revolution, then

space passed over by $P = 2 \times 18 \times 3{\cdot}1416$.

Now while the handle makes 1 revolution the rack is raised 6 teeth;

$$\therefore \text{space passed over by the rack} = 6 \times \tfrac{1}{2} = 3 \text{ in.}$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{2 \times 18 \times 3{\cdot}1416}{3} = 37{\cdot}7 \text{ nearly.}$$

And on the principle of work, the pressure produced upon the rack will be 37·7 times the pressure applied at the handle.

74. This figure shows a combination of more power; where the pinion r acts upon the wheel R′, which carries the pinion r' giving motion to the rack.

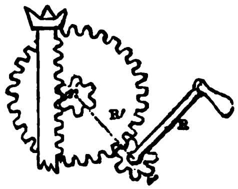


Fig. 66.

Ex. Let the length of the handle $=20$ in., number of teeth in $r=6$, number of teeth in $R'=30$, number of teeth in $r'=6$, and the distance between the teeth of the rack$=\frac{1}{2}$ in.; required the velocity ratio, as in the last example.

Let the pinion r' or the wheel R′ make 1 revolution, then

$$\text{No. revo. of } r \text{ or P} = \frac{30}{6} = 5,$$

$$\therefore \text{space passed over by the rack} = 6 \times \tfrac{1}{2} = 3 \text{ in., and}$$
$$\text{space passed over by P} = 2 \times 20 \times 3{\cdot}1416 \times 5;$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{2 \times 20 \times 3{\cdot}1416 \times 5}{3} = 209{\cdot}44,$$

which is the velocity ratio.

In this case the pressure produced on the rack will be 209·44 times the pressure applied at the handle.

SHAFTS AND AXES.

Coupling.

75. In the conveyance of motion by shafts, it is sometimes necessary to couple or connect one shaft with another; this is called *coupling*.

This cut shows a common mode of coupling the shafts A and B. Here the shafts are terminated with circular heads at *e* and *c*, on which teeth are cut, so that the projections of the one shall fit into the indentations of the other: thus motion is communicated from the shaft A to the shaft B; and should any settlement of the building cause any of the bearings of either shaft slightly to fall, these joints will admit of the derangement and still communicate the motion from the one shaft to the other.

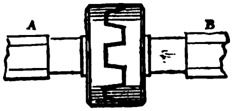


Fig. 67.

Universal Joint.

76. *The universal joint* furnishes another means of uniting shafts which are not exactly in the same direction.

This ingenious contrivance is shown in *fig.* 68.; where S and C are two shafts, the ends of which are formed like a fork; R is a circular ring, placed between the forks, with four pins or pivots, *a*, *b*, *c*, *d*, on its circumference, which work in corresponding holes made in the forks. By this simple contrivance motion may be communicated from one shaft to another, when the angle which they make with each other does not exceed about 15 degrees.

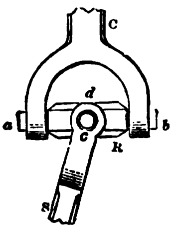


Fig. 68.

77. *Fig.* 69. represents the double universal joint. In the construction of this piece of mechanism, the extreme axes AB and CD should meet in a point, and the angles which they respectively make with the intermediate piece EF should be equal to each other.

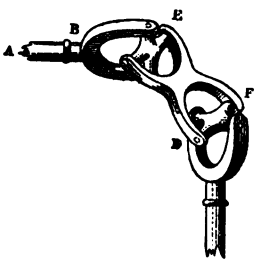


Fig. 69.

78. *Engagement and Disengagement of Machinery.*—On of the simplest and most effective contrivances for this pur pose is called the fast and loose pulley. Here s s represents the shaft to which motion is to be given; A and B are two pulleys, the one being fast and the other loose; the band which transmits motion may be shifted, at pleasure, from the one pulley to the other; and thereby putting the axle s s in motion or out of motion, or, as it is called, in gear or out of gear.

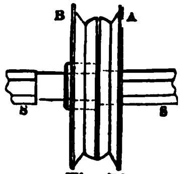


Fig. 70.

79. Another contrivance for the same purpose is here shown; where P P is a pulley, moved by a strap, revolving freely upon the round portion of the shaft A B, with which it is required occasionally to be connected in order to give motion to the machinery. For this purpose, the shaft has a cross piece of metal D E, called a gland, firmly attached to it; the pulley P has two or more teeth projecting on its side, so that when this pulley is made to slide towards the left by means of the lever G E, these teeth engage the arms or limbs of the gland, and thereby carry round the shaft A B with the pulley.

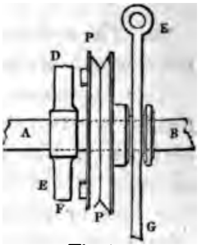


Fig. 71.

80. This figure represents a similar contrivance, where A B is a shaft to which machinery is attached and which is required to be put occasionally in motion; C C is a bevelled wheel, revolving freely upon the round portion of the shaft, and is kept constantly in motion by its connection with another bevelled wheel. That portion of the shaft marked A is square, and the clutch D is made to slide along it by means of the lever E F;

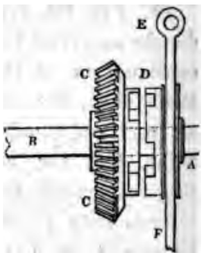


Fig. 72.

when the teeth in the clutch D are made to engage the corresponding teeth on the side of the wheel C C, the shaft A B then revolves with it.

81. Two bevel-wheels A and B, rotating freely when out of gear, are driven in contrary directions by the bevel-wheel C; either of these wheels may be fastened to the vertical axis H I by the sliding piece N *n* engaging the teeth *e e* or *c c;* by this means the vertical axis H I may be made to revolve in any required direction; the

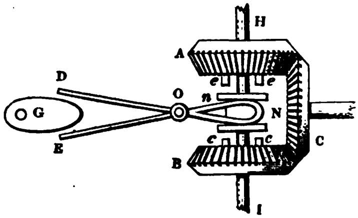


Fig. 73.

sliding piece N *n* is moved by the lever D O N E turning on the centre O; an eccentric wheel G, to which a vibrating motion is given by some parts of the machinery, may be employed to bring the wheels A and B alternately in gear.

Gudgeons.

82. *Gudgeons* are those circular portions of a shaft upon which machinery revolves.

In cast-iron shafts these gudgeons are simply portions of the shaft turned perfectly circular in a lathe. The parts in which the gudgeons turn are called *brasses:* thus in the figure, *c* represents a gudgeon turning in its brasses, which are here shaded dark. These brasses are made of a

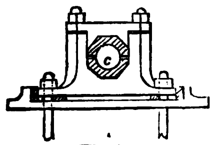


Fig. 74.

composition of copper and tin, which is not only durable but works with very little friction with iron.

83. In a vertical cast-iron shaft S, the pivot P is usually made of an egg shape. Another method consists in having the end C flat, with an oblong notch in it which fits upon a round piece of steel A A, having a groove *a* in its under side to admit of oil.

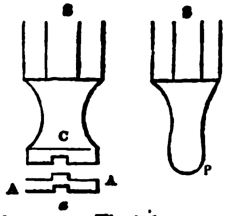


Fig. 75.

84. When iron gudgeons are placed upon wooden shafts, some attention must be paid to the mode of connection, so as to secure durability and steadiness.

This figure shows a mode of fixing an iron gudgeon upon a wooden shaft; where s is the shaft; G the gudgeon with a cross, *ce*, upon it, which is let into the end of the wooden shaft s. The cross is made of a wedge shape, having the front edge thinner than the back, so as to admit of being firmly driven into the end of the shaft, which has a strong iron hoop put round it to prevent it from splitting.

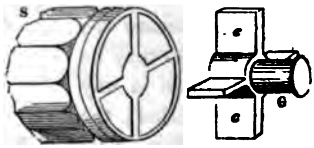


Fig. 76.

FRICTION WHEELS.

85. Here the axis C, of the wheel A, rests between two frictional wheels, *a*, *b*, which turn upon their axes, *e*, *e*. As the wheel A revolves, its axis C, having a rolling contact with the friction wheels *a* and *b*, causes them to turn upon their axes, *e*, *e*, so that the friction is transferred from the axis C, of the large wheel A, to the axes, *e*, *e*, of the two friction wheels. If the circumference of each friction wheel be 9 times that of its axis, then the extent of the surface rubbed over by the axis *e* will be $\frac{1}{9}$ of that which is rubbed over by the axis C upon each friction wheel; and the friction will thus be reduced in nearly the same

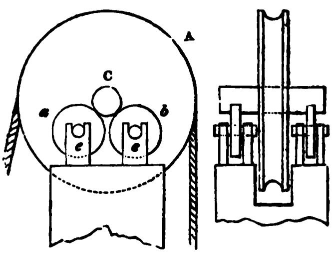


Fig. 77.

ratio. The pressure upon each axis of the friction-wheels will be one-half the pressure upon the axis C of the large wheel. Friction-wheels are used in delicate pieces of mechanism, such as in Atwood's machine for demonstrating the laws of motion and falling bodies, where it is essential that the friction should be eliminated as far as possible.

CONCENTRIC WHEELS.

86. Two separate wheels may revolve concentrically, that is, about the same centre, as in the case of the hour and minute hands of a watch or clock.

The wheel D is fixed to the axis DCE, and the wheel C to a tube or *cannon* N, which revolves freely upon the axis DCE. The hour hand H is attached to the cannon N, and the minute hand M to the axis DCE. The driving-wheels A and B, fixed to the axis AB, communicate the relative velocities to the axis DE and the cannon N. Let A contain 40 teeth, B 12, C 36, and D 10; then while the wheels A and B perform 3 revolutions, the wheel D with its pointer M will perform 4 times 3 or 12 revolutions, and the wheel C with its cannon and pointer H will perform 1 revolution; that is, the pointer M will make 12 revolutions in the same time that the pointer H makes one.

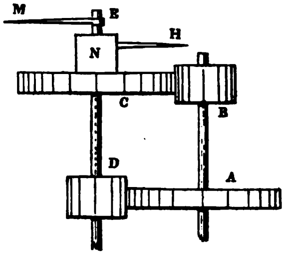


Fig. 78.

87. When the concentric wheels C and D are required to revolve in contrary directions, this is readily effected by the intervention of a single bevel-wheel A, the cones having a common apex *e*. In this arrangement A is

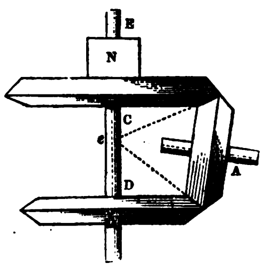


Fig. 79.

called an idle wheel, as it merely serves to connect the teeth in the wheel D with those in the wheel C, and the velocity ratio of D and C will solely depend upon their number of teeth: thus if C has 48 teeth and D 12, then D will make 4 revolutions while C makes one.

RATCHET WHEELS.

88. It frequently happens where wheels are used in machinery, that the action of the moving power is suspended for a time, or undergoes periodic intermission, in such cases some contrivance is required to prevent the recoil of the wheels. For this purpose a ratchet wheel R with a *detent* D is usually employed. This contrivance allows the wheel to turn in one direction, but the catch or detent, falling into the angular teeth of the ratchet wheel, prevents it revolving in the opposite direction A spring is sometimes used to give a slight pressure to the detent against the ratchet wheel. This piece of mechanism is invariably employed in cranes and other machines for raising heavy weights by the application of aninal power.

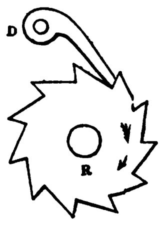


Fig. 80.

INTERMITTENT MOTIONS IN WHEELS.

89. Motions of this kind may be produced by the four following ingenious contrivances:—

90. Here C and D are two common spur wheels, C being the driver and D the follower, where the teeth are cut away from the part A E B. When the teeth A B are engaged with the teeth on D, this wheel revolves in the usual manner, but on the *contrary,* when the plain portion A E B is passing the line

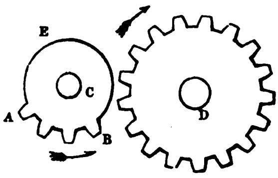


Fig. 81.

of centres, the wheel D remains at rest, so that while the driver C has a continuous circular motion, the follower D has an intermittent circular motion.

This mechanism is liable to the following objection, viz. the chance of the first tooth B, in the wheel C, not exactly engaging with the teeth on D; however, this is readily obviated by the introduction of a guide-plate, as in the following contrivance:—

91. Here A is a driving-wheel having *sunk* teeth on its edge from *c* to G; B is the follower, to which an intermittent motion is to be given, having corresponding teeth cut upon its edge excepting at the portion *c d*, which is a plain arc of a circle described upon A as a centre. P is a pin fixed in the wheel A, and S a guide-plate fixed to the face of the wheel B. Now when A revolves, the plain portion of its edge runs past *c d* without touching it; and at the same time prevents B from shifting its position, but when the pin P comes in contact with *the guide-plate* S, the wheel B is turned round, and the teeth *c* G engage themselves with the teeth on B, so that B is constrained to make one revolution, and then after that it remains at rest until the pin P again comes round to engage the guide-plate.

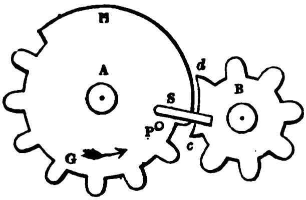


Fig. 82.

92. Here A is the driving-wheel having only one tooth *t* upon it; B the follower, to which an intermittent motion is to be given. In each revolution made by A only one tooth in B is moved round, so that during the greater portion of the revolution of A the wheel B remains at rest. The detent D retains the wheel B in the position to which it is successively moved by the tooth *t*.

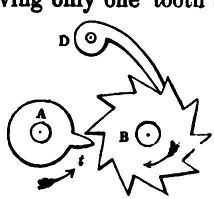


Fig. 83.

93. This figure represents an intermittent motion which has been introduced into the mechanism of the Geneva watches. A is the driving wheel, revolving constantly in the same direction, and B the follower, to which an intermittent motion is to be given.

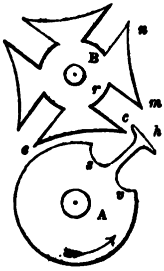


Fig. 84.

The edge of B is notched, as shown in the figure, and the portions *e c*, *m n*, &c., are arcs of circles concentric with the centre of A when they are placed opposite to it. The wheel A has a hatchet-shaped tooth *h* upon it, with the parts *s* and *v* on each side cut away in order to make room for the points *c*, *m*, &c. When A revolves no motion takes place in B until the hatchet-tooth *h* strikes the side *c* of the recess *c r m*, and carries the wheel B through the space of one tooth, and brings the next arc *m n* opposite to the plain edge of A, which retains B until the hatchet-tooth has performed another revolution.

94. The crown wheel *a*, turning continuously on its vertical axis A, and having only a few teeth cut on its edge, may be made to give an intermittent rotation to a horizontal axis *d e*.

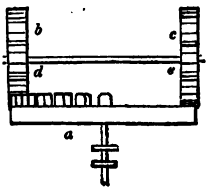


Fig. 85.

Let the two wheels *d b* and *e c* revolve upon the horizontal axis *d e*, then as the crown wheel *a* revolves continuously, the wheel *d b* will be driven in one direction, and the wheel *e c* in a contrary one, as their teeth become alternately engaged; so that the axis *d e* will alternately revolve in opposite directions. In this case the teeth on the crown wheel should not occupy more than one-half its circumference.

WHEELS PRODUCING BY ROLLING CONTACT A VARIABLE MOTION.

95. Let D*m*P and C*n*P be portions of two curved wheels in contact at the point P, and revolving on the centres D and C respectively, then in order that these two wheels may roll on each other without slipping or without exerting any strain upon the centres D and C, these centres must be in the line of contact CPD; and moreover, if the curve *n*P be equal to the curve *m*P, the sum of the lines C*n* and D*m* must be equal to the sum of the line CP and DP, and so on to any other coincident points of mutual contact.

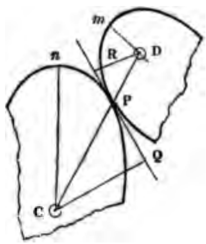


Fig. 86.

If D*m*P and C*n*P be two equal ellipses revolving on their foci D and C respectively, *n* and *m* being the extremities of their major axes, then these elliptical wheels will have a perfect rolling contact. In like manner two equal logarithmic spirals have the same property.

96. *To find the velocity ratio of the wheels.* Let QPR be the common tangent to the point P of the two curves; and let CQ and DR be perpendiculars upon this tangent. Here the velocity of the point P on the two wheels is obviously the same, hence we have Art. **30.**,

$$\text{ang. velo. CP} = \frac{\text{velo. P}}{\text{CQ}},$$

$$\text{and ang. velo. DP} = \frac{\text{velo. P}}{\text{DR}},$$

$$\therefore \frac{\text{ang. velo. CP}}{\text{ang. velo. DP}} = \frac{\text{DR}}{\text{CQ}} \text{ or } \frac{\text{DP}}{\text{CP}},$$

that is to say, *the angular velocities of the wheels are inversely as the perpendiculars let fall upon the common tangent from the centres of motion.*

97. The form of wheels represented in this figure, is one of the most approved methods of obtaining a varying velocity ratio. It is that which is used in silk-mills, and in the Cometarium. The form of the curves must be such as to answer the conditions explained in Art. 95.

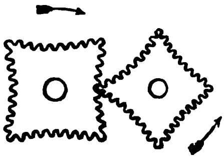


Fig. 87.

98. This figure represents a method of producing a varying angular velocity ratio by means of ordinary spur-wheels. D is a common toothed wheel turning upon an eccentric centre of motion B; A is the wheel to which a varying velocity is to be given by the uniform angular motion of D; C is a pinion with teeth of the same gauge as those on D and A. The centre of this pinion is moveable, being carried by the arm AC, which revolves upon the centre A, so that while the eccentric wheel revolves, the arm AC rises and falls to suit the position of the eccentric. The link DC connects the centres of the two wheels D and C in order to keep their teeth in gear.

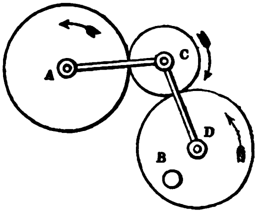


Fig. 88.

99. *Roëmer's Wheels.* These wheels were invented by Roëmer, the astronomer, to produce the varying velocities of machines intended to represent the planetary motions. A and B are two conical wheels having their vertices towards opposite sides; A has teeth like those of the common bevel-wheels; upon the surface of B are fixed a series of pins in such manner as to fall in succession into the spaces between the teeth on A. As the pins towards *e* must be more apart

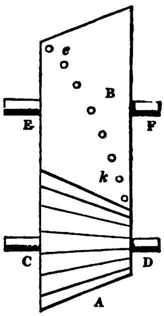


Fig. 89.

than they are towards *k*, and also at the same time nearer the centre of motion, it is obvious that the rotation of B will be accelerated as the former teeth become engaged. By varying the position of the pins with respect to the edge of the wheel, any velocity ratio may be obtained.

100. A varying angular velocity may be obtained by an eccentric crown wheel A, and a long cylindrical pinion P; where the axis *cd* of the crown wheel is eccentric to its circumference, and the axis of the pinion P is at right angles to *cd* and meets it in direction. Supposing the driver P to revolve uniformly, then the follower A will have the greatest angular velocity when the teeth at *v* nearest the centre of motion are engaged, and the least angular velocity when the teeth at *e* furtherest from centre of motion are engaged.

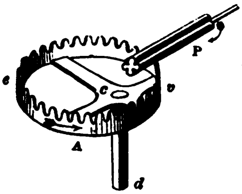


Fig. 90.

CHAP. VI.

SLIDING PIECES, PRODUCING BY SLIDING CONTACT, SLIDING MOTIONS.

101. THE inclined plane, the wedge, the camb, and the screw are simple machines, in which the action of sliding pieces is employed.

INCLINED PLANE.

102. Let A C represent an inclined plane, A B its horizontal base, B C its vertical height, and B A C its angle of elevation.

Let W be the weight placed upon the plane, and P the power drawing up this weight, by means of the cord PBW passing over the pulley BD, the cord DW, in this case, being parallel to the plane.

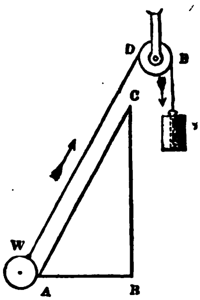


Fig. 91.

To find the ratio of the vertical velocities of P and W. Here while W moves from A to C, it will have been raised the vertical height BC of the plane, and the cord DW being shortened a space equal to AC, P will have descended a space equal to AC the length of the plane; hence, the velocities of P and W, estimated in a vertical direction, will be to each other as the length of the plane to its height, that is,

$$\frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{length of the plane}}{\text{height of the plane}} \text{ or } \frac{\text{AC}}{\text{BC}} \ldots (1).$$

This velocity ratio is obviously constant for all positions of W on the plane.

Now in all machines we have $\frac{\text{W}}{\text{P}} = \frac{\text{velo. P}}{\text{velo. W}}$; therefore $\frac{\text{W}}{\text{P}}$ $= \frac{\text{AC}}{\text{BC}}$.

Or thus going over all the steps of the operation. While W passes over a vertical space equal to the height of the plane, P descends a space equal to the length of the plane; hence we have

$$\text{work applied by P} = \text{P} \times \text{AC},$$
$$\text{work done upon W} = \text{W} \times \text{BC},$$

$$\therefore \text{W} \times \text{BC} = \text{P} \times \text{AC},$$

$$\text{or } \frac{\text{W}}{\text{P}} = \frac{\text{AC}}{\text{BC}} \text{ or } \frac{\text{length of the plane}}{\text{height of the plane}}, \ldots (2);$$

that is to say, W will be as many times P as the length of the plane is that of its height. Thus if the length of the plane be double its height, then the weight would be double the power and so on.

103. The inclined plane as a mechanical power is generally used in connection with frictional rollers. In this way workmen are enabled to raise heavy stones into a cart as shown in this figure. As the rollers are disengaged at the lower end of the stone, they are put in at the upper end, so that three or more rollers are kept continually beneath the stone as it is being rolled forward.

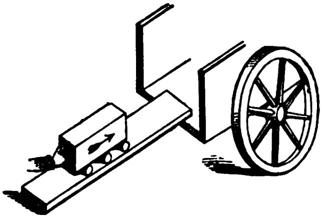


Fig. 92.

104. Suppose the cord DW to form any angle DWC with the plane. Let W move over the very small space Ww; from D describe the arc wq, and draw Wk parallel to AB and wk perpendicular to it; then the cord WD will be shortened a space equal to Wq, and P will therefore descend a space equal to Wq; but W will ascend a vertical space equal to wk; therefore Wq will be the vertical velocity of P, and wk the vertical velocity of W;

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{W}q}{wk}.$$

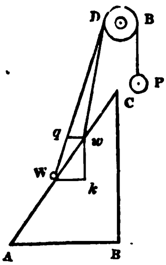


Fig. 93.

Now when Ww is indefinitely small the arc wq becomes a straight line perpendicular to WD; hence we have

$$\text{W}q = \cos. \angle \text{DWC} \times \text{W}w,$$

$$\text{and } wk = \sin. \angle k\text{W}w \times \text{W}w = \sin. \angle \text{BAC} \times \text{W}w;$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{W}q}{wk}$$

$$= \frac{\cos. \angle \text{DWC} \times \text{W}w}{\sin. \angle \text{BAC} \times \text{W}w}$$

$$= \frac{\cos. \angle \text{DWC}}{\sin. \angle \text{BAC}},$$

which is the velocity ratio of P and W, estimated in a vertical direction. Now as the ∠BAC is constant, this velocity ratio will vary as the cos. ∠DWC, or as the cosine of the angle which the cord makes with the plane; and if this angle be constant, that is, if the force acting along WD be always parallel to itself, the velocity ratio of P and W will be constant.

105. Now for the condition of equilibrium, we have

$$\text{work of P} = \text{P} \times \text{W}q; \quad \text{work of W} = \text{W} \times wk;$$

$$\therefore \text{W} \times wk = \text{P} \times \text{W}q,$$

$$\therefore \frac{\text{W}}{\text{P}} = \frac{\text{W}q}{wk}$$

$$= \frac{\cos. \angle \text{DWC}}{\sin. \angle \text{BAC}}.$$

THE WEDGE.

106. The wedge is merely a moveable inclined plane. Let ABC represent a moveable inclined plane or wedge, sliding along the surface HR by the force of a pressure P applied to the back BC of the wedge in a direction parallel to HR: and let W be a heavy rod resting upon the inclined side AC, and constrained to move in a vertical direction by means of the guide rollers E, F, G, H. As the wedge is being pushed forward, the rod DW will be raised, so that while the wedge has passed over a space equal to its length BA, the rod will have been raised through a space equal to the thickness BC of the wedge; that is, while the pressure P has passed over a space equal to AB, the weight W has passed over a space equal to BC;—

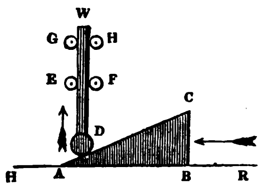


Fig. 94.

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{AB}}{\text{BC}} \text{ or } \frac{\text{the length of the wedge}}{\text{the thickness of the wedge}},$$

which is the velocity ratio of the power to the resistance. *This velocity ratio* is obviously the same for all positions.

107. To obtain the conditions of equilibrium. While the weight W lbs. is raised over the vertical space CD, the pressure of P lbs. moves over the space AB, hence we have

$$\text{work of } W = W \times BC, \quad \text{work of } P = P \times AB,$$

$$\therefore \; W \times BC = P \times AB,$$

$$\therefore \; \frac{W}{P} = \frac{AB}{BC};$$

that is to say, W *will be as many times* P *as the length of the wedge is that of the thickness.* Thus if the length of the wedge be double its thickness, then the resistance, W, overcome, will be double the pressure, P, applied; and so on.

108. Here *fig.* 1. shows the form of the wedge as it is employed in splitting timber; where CE is the length, DC

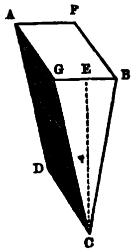


Fig. 95. (1.)

Fig. 95. (2.)

the edge, and GB or AF the thickness. In *fig.* 2. the resistance acting at F arises from adhesion of the material that is being split, and the power applied at AB, is the impetus given by the stroke of a heavy mallet. The great power of the wedge, used in this manner, depends almost entirely upon *the work*, accumulated in the mallet, being at once delivered upon the head of the wedge.

109. The wedge is also an indispensable agent in the *winnowing of stones* out of quarries. It is also frequently employed in raising great weights for a short distance; in such cases two wedges are made to act together as in the annexed figure; where A B *d c* and *d b a c* represent two similar wedges employed for raising the mass W, by simultaneous strokes given to the heads A *c* and *d b*. It is evident that the plane of *a b* will always be parallel to A B.

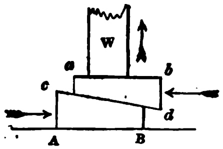


Fig. 96.

CAMBS.

110. These important elements of mechanism consist of irregular pieces of material, to which a rotatory motion may be given for the purpose of producing reciprocating motions in rods and levers. Here F H I J represents the camb; A its centre of motion; A B a handle; C D the rod to which a vertical reciprocating motion is to be given. As the handle is being turned in the direction of the arrow, the rod C D has an upward motion until the point F comes in a line with the rod, then, as the handle is still being turned, the portion F H of the camb permits the rod to fall by its own weight, or by the action of a spring, until H comes in a line with the rod, and so on; so that in one revolution of the handle, the rod (in this form of camb) will make three upward and three downward strokes. Supposing the handle to revolve uniformly, any law of motion may be given to the rod C D, by the peculiar form given to the curve of the camb.

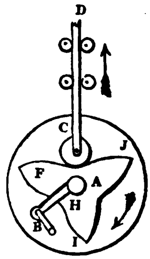


Fig. 97.

111. In order that the pressure of the camb may produce the downward as well as the upward stroke, the pin or the extremity of the rod may be made to traverse

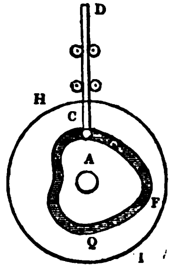


Fig. 98.

a groove cut in the camb plate, as in this figure; where CD is the rod with its pin or extremity C fitting into the groove CQF forming the camb.

112. To find the form of the camb, so that the velocity ratio of the wheel, or handle, and the rod may be constant.

Let QACG be the direction of the rod, and C the centre of the camb. With C as a centre, and any convenient radius CA, describe the circle ABD. Take A*a* equal to the length of the stroke of the rod, and divide it into any number of equal parts, say 5, in the points *b*, *c*, *d*, *e*; and divide the semicircle ADG into the same number of equal parts by the radial lines CB, CD, &c. With C as a centre and C*b*, C*c*, C*d*, &c., as radii describe circles, cutting CB, CD, CE, &c., respectively in the points *r*, *s*, *t*, &c.; through these points draw the curve *arstv*G, and similarly on the other side draw the curve *ak*G; and it will give the form of the camb required.

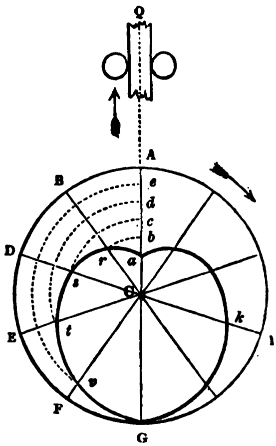


Fig. 99.

All lines drawn through the centre of the camb are equal, that is, $aG = sk = \&c.$

$$\text{Because } Cs = Cc = Ca + 2ab,$$
$$\text{and } Ck = Cd = Ca + 3ab,$$
$$\therefore\ sk = Cs + Ck$$
$$= 2Ca + 5ab$$
$$= 2Ca + aA$$
$$= Ca + CA$$
$$= aG.$$

Hence, if the rod had two pins, placed at *a* and G, the camb would revolve between them, and would produce a downward as well as an upward stroke of the rod.

This curve is the spiral of Archimedes; for while the radius vector C*a* revolves uniformly, the point *a* also moves uniformly along it.

By dividing the line *a*A into parts having a varying proportion to each other, any assignable law of velocity may be given to the rod.

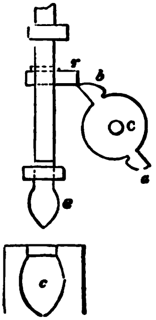


Fig. 100.

113. When the rod is to receive a series of lifts with intervals of rest, the camb assumes the form of teeth which are called *wipers* or tappets. Here C is a wheel revolving on its axis; *a* and *b* wipers which act in succession upon the tooth *r* upon the vertical rod or stamper *er*. In one revolution of the wheel the stamper makes two lifts, and the pestle *e* falls two times into the mortar *c*.

114. Here a cylinder *a* has 5 wipers upon it. The hammer *b* turns upon a lever *bc* whose axis is C; the extremity *e* of the lever is depressed by the wipers, and thus the hammer is raised; but the moment the wiper disengages itself from the lever, the hammer falls by its weight and strikes the heated iron placed upon the anvil A.

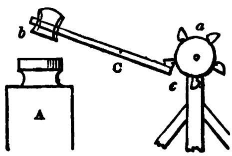


Fig. 101.

In this case, the hammer would make five lifts and five strokes for every revolution of the wheel.

115. Here *a* is the wheel, turning upon the axis *en*, having a series of cambs cut upon its face. The cambs communicate an alternating motion to the rod *bs*, which moves between the guides *c* and *d*, and is kept constantly pressing against the cambs by a spring *s* fixed to its extremity.

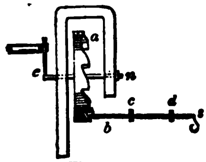


Fig. 102.

THE SWASH PLATE.

116. Here DEO is a revolving axis, carrying with it an inclined plate AG called a swash plate; ABC a rod capable of moving in the direction of its length only, having guides or friction rollers at B and C. This rod is kept in contact with the plate by its own weight or by means of a spring. Now owing to the inclined position of the swash plate, as it turns round, the rod AC is alternately elevated and depressed, so that the continuous circular motion of the axis DE produces a reciprocating motion in the rod AC in the direction of its length.

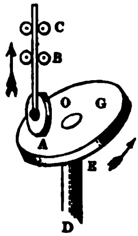


Fig. 103.

ESCAPEMENTS.

117. Escapements are used in clock-work for converting a continuous circular motion into a reciprocating one.

CROWN-WHEEL ESCAPEMENT.

118. This escapement is commonly used when the axes are at right angles to each other.

Here A is the revolving axis, and B the crown-wheel fixed to it, having large saw-shaped teeth; CD is *the verge* which vibrates with the pendulum QR. This verge carries two *pallets*, *o* and *c*, the planes of which form an angle with each other, so as to admit of the escapement motion. Supposing the crown wheel to be revolving

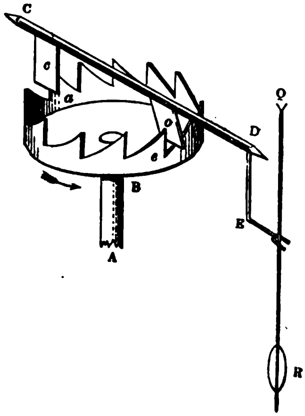


Fig. 104.

in the direction of the arrow, the tooth *e* by pressing upon the pallet *o* causes the verge CD to turn in the same direction, until the pallet *o* allows the tooth *e* to pass under it, now at this instant the pallet *c* is brought into contact with the tooth *a*, which now presses upon this pallet and turns the verge back to its first position, when the tooth *a escapes* from under the pallet *c*, and then another tooth is brought to act upon the pallet *o*, and so on to any number of vibrations. By this means the revolution of the crown wheel sustains the oscillations of the verge CD. The arm DE is attached to the verge and vibrates with it; this arm has a fork at its extremity through which the rod of the pendulum QR passes, so that the vibrations of the verge are transmitted to the pendulum, and vice versâ.

ANCHOR-ESCAPEMENT.

119. When the axes of the verge and wheel are parallel to each other, the anchor-escapement is commonly used.

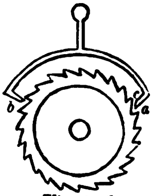


Fig. 105.

Here D is the centre of the revolving wheel, and C that of the anchor-escapement C*ba*; in this case the extremities of the pallets *a* and *b* are formed so as to fit those portions of the ratchet-teeth which act upon them. The action in this escapement is precisely the same as in the last one.

Escapements have received a great variety of forms.

THE SCREW.

120. A screw may be regarded as an inclined plane formed upon the surface of a cylinder. In order to render this apparent, let *afg* be a cylinder, or common round ruler, and let *akg′* be a piece of paper cut in the form of an inclined

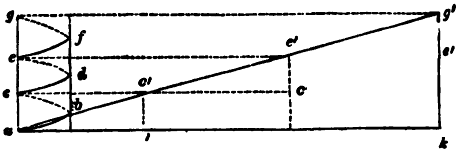


Fig. 106.

plane, whose height kg' is equal to the height ag of the cylinder; now if this paper be wrapped round the cylinder, the edge ag' will trace the spiral line $abcdefg$ upon the surface of the cylinder; and if a groove be made along this spiral it will form the thread of a screw. If ai be equal to the circumference of the cylinder, $c'i=ac$ will be the distance between the threads of the screw, and the angle of the threads of the screw is the angle kag'.

121. Let *cname* be a spiral groove cut upon a cylinder as described in the last article; CD the axis upon which the cylinder turns; AB a rod parallel to the axis CD, and having a pin or tooth *c* fitting the groove of the screw. Now when the handle CP is turned in the direction of the arrow, the pin *c*, with its rod AB, is moved towards the right; so that in one revolution the pin will have moved from *c* to *a*, the distance between the threads of the screw, and in the second revolution it will have moved from *a* to *e*, and so on. The rod AB will thus be moved in a rectilinear path.

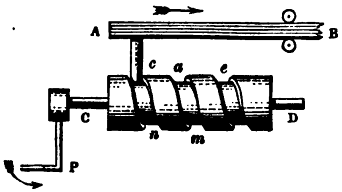


Fig. 107.

To find the velocity ratio of the extremity P of the handle and the rod A B. Let P make one revolution, then the pin *c* will move from *c* to *a*, that is, the rod A B will be moved over a space equal to the distance between two contiguous threads:

∴ space moved over by P=circum. described by P.

Space moved over by the rod AB=the distance between the threads. Hence we have

$$\frac{\text{velo. P.}}{\text{velo. A B}}=\frac{\text{circum. described by P.}}{\text{distance between the threads}}.$$

It is evident that this velocity ratio must be constant.

122. In the place of having only one tooth *c*, it is evident that we might also have teeth at *a*, *e*, &c., and instead of square threads we might have them triangular, without in the least affecting the motion. This arrangement is shown in the annexed figure; where *n c*, *m a*, &c., are the threads

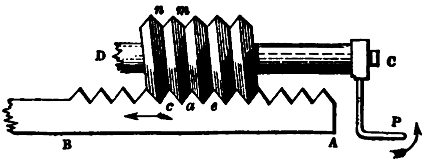


Fig. 108.

of the screw; *c*, *a*, *e*, &c., the teeth upon the *rack* A B; and CP the handle which drives the screw. This arrangement is called *the rack and screw*, by which a continuous circular motion is converted into a continuous rectilinear one.

The teeth upon the rack or comb are made exactly to fit the threads of the screw, so that these teeth may be regarded as forming a portion of a reverse screw.

123. In most cases, however, the piece AB, which undergoes the action of the screw, has its teeth or rather threads formed in a cavity embracing the whole circumference of the screw, and fitting its threads exactly; this modification is shown in *fig.* 109, where N is the hollow screw fitting the threads of the solid screw S.

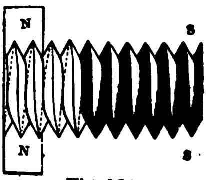


Fig. 109.

This hollow screw is called the female screw, and S the male screw. The whole piece N is called a *nut*.

The threads of screws are made of dif-'orms: thus in *fig.* 109., the threads are lar, whereas those in *fig.* 110. are square. case BCDE is the cylinder upon which ew is cut; *a d* the thickness of the and *a b* its depth.

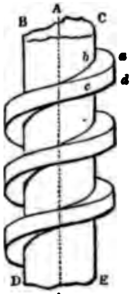


Fig. 110.

In the application of the screw to ma- there are three cases which merit con- on: —

1. When the hollow screw or nut is ely fixed, the solid screw will have a dinal motion when it is turned.

2. If the solid screw revolves without having any dinal motion, as in *figs.* 107. and 108., the nut will have ;udinal motion, provided it is incapable of revolving.

3. If the nut revolves, without having any longitu- ιotion, the solid screw will have a longitudinal motion, d it is incapable of revolving.

The common Press.

The screw is used in cases where a great pressure is ɛerted through a small space. mmon press is one of the ɛeful applications of this me- l power.

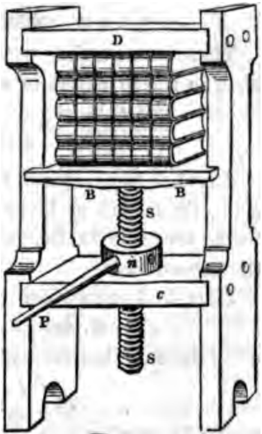


Fig. 111.

111. represents a book- ı press, where S S is the rew working in the hollow r nut *n*, resting on the fixed '; B the press board, fixed op of the screw, and admits ʒ moved vertically between s of the frame. As in Case 125., the solid screw S S is le of revolving, but moves linally or in the direction of

its length; whereas the nut *n* revolves, but does not move longitudinally, or in the direction of the length of the screw. The nut is turned by means of the lever P, which is inserted in the holes formed on the edge of the nut. The material to be compressed is placed between the press-board B and the fixed beam D.

This press is also made to act after the manner of Case I., Art. **125.** In this form the perforated cylinder *n* is fixed to the solid screw S S, and therefore turns with it, on a pivot turning in a socket on the under side of the press-board B; the piece *c*, fixed to the solid frame, contains a female or hollow screw, whose threads exactly correspond to those on the solid or male screw S S; so that when this solid screw is turned round by the handle P, it ascends through the hollow screw formed in the fixed board *c*, and thus raises the press-board B, which only admits of being moved vertically.

In one turn of the lever P, the screw S S, with its press board B, is moved upwards a space equal to the distance between the threads of the screw. Hence we have, as in Art. **121.**,

$$\frac{\text{velo. P}}{\text{velo. B}}=\frac{\text{circum. described by P}}{\text{distance between the threads}}.$$

Therefore, putting W for the pressure produced on B, we have in the principle of work, Art. **14.**: —

$$\frac{\text{W}}{\text{P}}=\frac{\text{velo. P}}{\text{velo. B}}=\frac{\text{circum. described by P}}{\text{distance between the threads}}.$$

Ex. Let the distance between the threads of the screw= $\frac{1}{4}$ in., the length of lever=48 in., and the pressure P applied to the lever=160 lbs., required the pressure W produced on the press-board.

Here in 1 revolution of the lever,

circum. described by $\text{P}=2\times 48\times 3{\cdot}1416$,

distance between the threads$=\frac{1}{4}$, and $\text{P}=160$ lbs.

$$\therefore \frac{\text{W}}{160}=\frac{2\times 48\times 3{\cdot}1416}{\frac{1}{4}};$$

$\therefore \text{W}=2\times 48\times 3{\cdot}1416\times 4\times 160=193010$ lbs. nearly.

127. *Fig.* 112. represents another form of the press; where the press-board D is placed at the under end of the screw, and the nut at the upper part of the frame. This is the form usually given to presses for compressing the liquids or juices from fruit, &c.

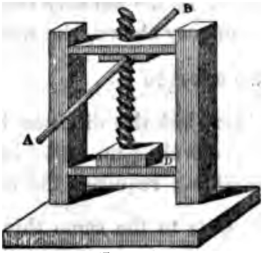


Fig. 112.

Compound Screw.

128. This ingenious contrivance consists of two screws A and B having different thicknesses of threads. The larger screw A has a hollow screw turned within it exactly fitting the screw upon B, so that when A is turned round, B screws into the interior of A. The exterior screw of A passes through a fixed nut n secured to the frame C D. The screw B is capable of moving in the direction of its length Bd, but is incapable of revolving.

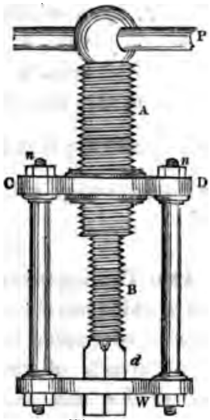


Fig 113.

Let P be the pressure applied to the lever P, and W the pressure produced at the point W. In one revolution of the lever, the screw A descends a space equal to the distance between its threads; but at the same time, the screw B enters into the hollow screw, in A, a space equal to the distance between the threads on B; therefore the point W will only descend a space equal to the difference of the distances between the threads on A and the threads on B:—

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{circum. described by P}}{\text{dist. bet. threads of A} - \text{dist. bet. threads of B}}$$

E 2

which is the velocity ratio of P and W. Now, as we have frequently shown, the right hand member of this equality is also equal to $\frac{W}{P}$.

Ex. Let the distance between the threads on A and B be respectively $\frac{3}{8}$ in., and $\frac{1}{4}$ in., and let the length of the lever be 60 in.; required the velocity ratio of P and W, or, what amounts to the same thing, the value of $\frac{W}{P}$.

Let P perform one revolution, then

$$\text{space passed over by P} = 2 \times 60 \times 3{\cdot}1416;$$
$$\text{space which the screw A descends} = \tfrac{3}{8},$$
$$\text{,, ,, ,, ,, B ascends} = \tfrac{1}{4},$$
$$\therefore \text{space which the point W descends} = \tfrac{3}{8} - \tfrac{1}{4} = \tfrac{1}{8};$$
$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{2 \times 60 \times 3{\cdot}1416}{\frac{1}{8}} = 3016 \text{ nearly};$$

that is to say, the velocity of P will be 3016 times that of W; and $\frac{W}{P} = 3016$; that is to say, W must be 3016 times P, which is the advantage gained by the press.

The Differential Screw.

129. This ingenious contrivance consists of a solid cylinder *h a g*, which has three screws cut upon it. The threads of the screws *h e* and *b a* have the same inclination and thickness, but the threads of the screw *d c* have a different inclination.

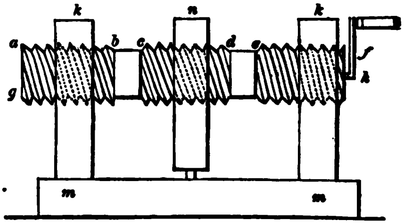


Fig. 114.

The screw *h e* works in a hollow screw cut in the fixed block *m k*, and *a b* in a similar screw cut in the other fixed block; *n* is a nut having a hollow screw cut in it, corresponding to the threads on *c d*, and capable of moving *longitudinally* but incapable of revolving from the intervention of guides. Let the handle $h f$ make one turn, so as to move the cylinder from left to right, then the nut n will be moved, from right to left on the screw $d c$, a space equal to the distance between its threads, but at the same time it will be moved with the cylinder, from left to right, a space equal to the distance between the threads of the screw $a b$; therefore in one revolution of the handle,

the space moved over by the nut
=thickness threads on $a b$—thickness threads on $d c$.

The Endless Screw.

130. When the threads of a screw are made to act upon the teeth of a wheel, the mechanism is called the endless screw. Here the distance between the teeth of the wheel K, must be equal to the distance between the threads of the screw AD. Let P be the pressure applied to the handle P, and W the weight suspended by the cord going round the axle C of the wheel K. Now

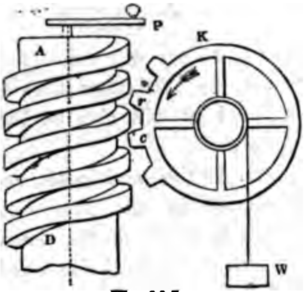


Fig. 115.

in every revolution of P one tooth of the wheel K must be turned round; therefore as many teeth as there are in K, so many turns must P make in order to turn the wheel K round once; but when the wheel K turns round once, the weight W must descend a space equal to the circumference of the axle C; hence in one revolution of the wheel K we have

Space descended by W=circum. axle,
No. turns of P=no. teeth in the wheel,
∴ space passed over by P
=circum. described by P × no. teeth in the wheel,

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{circum. descr. by P} \times \text{no. teeth in the wheel}}{\text{circum. of the axle}},$$

which is the velocity ratio of P and W; and this also expresses the value of $\frac{W}{P}$.

Ex. Let the number of the teeth in the wheel=60, the diameter of the axle=5 in., and the radius of the handle =30 in.; required the velocity ratio of P and W.

Let the wheel perform one revolution, then

Space passed over by W=5 × 3·1416;

No. revolutions of P=60,

∴ space passed over by P in 1 revo.=2 × 30 × 3·1416,

∴ space passed over by P in 60 revo.=2 × 30 × 3·1416 × 60;

$$\therefore \frac{\text{velo. P}}{\text{velo. W}}=\frac{2\times 30\times 3{\cdot}1416\times 60}{5\times 3{\cdot}1416}=720;$$

that is to say, the velocity of P will be 720 times that of W; and W will also be 720 times P.

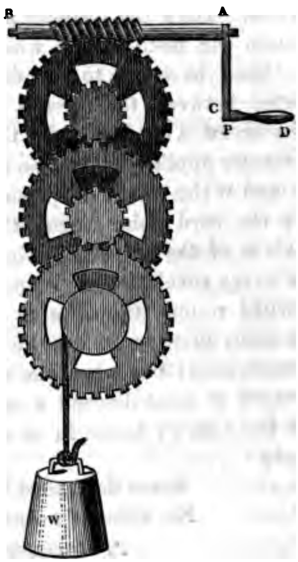


Fig. 116.

131. In the mechanism, represented in the preceding figure, the axis of the screw is vertical; but in the annexed figure the axis is shown in a horizontal position.

This figure represents a combination of very great mechanical power. There is an endless screw, with 3 toothed wheels, 2 pinions, and one axle, round which the cord suspending the weight W coils.

Ex. Let the radius, AP, of the handle=20; the no. teeth in the first, second, and third wheels 30, 60, and 40 respectively; the no. teeth in the first and second pinions 1 and

8 respectively; and the diameter of the axle 5 in.: required the velocity ratio of P and W.

Let the third wheel turn round once, then the no. turns of the second pinion will be 5, for $\frac{40}{8}=5$; no. turns of the first pinion or the first wheel will be 30, for 5 times $\frac{60}{10}=30$; no. revolutions of P will be 900, for 30 times 30=900:

$$\therefore \text{ space passed over by } W = 5 \times 3{\cdot}1416,$$

$$\text{and space passed over by } P = 2 \times 20 \times 3{\cdot}1416 \times 900;$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{2 \times 20 \times \cancel{3{\cdot}1416} \times 900}{5 \times \cancel{3{\cdot}1416}} = 7200,$$

which is the velocity ratio required; that is to say, the velocity of P will be 7200 times that of W; and the weight of W will be the same number of times the pressure applied at P.

Conical Screw.

132. This figure represents an arrangement for giving a rectilinear motion to the rod CD, when it is not parallel to the axis AB of the screw. This is effected by cutting the thread *en* upon the cone FGK, whose slant side FG is parallel to the rod CD. The tooth *e* upon the rod fits into the spiral groove *en*, so that when the cone is turned, the side of the groove or thread presses against the tooth and thereby moves the rod in the direction of its length. As the groove *en* is made everywhere of the same depth, it is evident that the rod CD must always be parallel to FG. Supposing the cone to revolve uniformly on its axis, then, in order that the motion of the rod should also be uniform, the path of the groove must be constructed after the method explained in Art. **112.** If the surface of the cone be developed, that is, if it be laid out on a flat surface, the groove *en* will be the spiral of Archimedes.

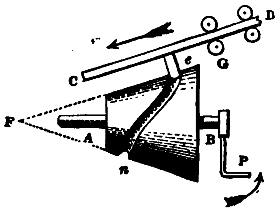


Fig. 117.

CHAP. VII.

MECHANISM CONSIDERED IN RELATION TO THE OBJECTS PROPOSED TO BE EFFECTED.

133. The preceding chapters of this work treat of the simple elements of mechanism, or forms of which all kinds of mechanism must consist, without any special regard to the objects to be effected by them. It will, however, be instructive to consider the forms of mechanism in relation to these objects. Taking this aspect of the subject, we shall consider,—1. Mechanism for regulating and accumulating motion; 2. Mechanism for modifying motion.

MECHANISM FOR REGULATING AND ACCUMULATING MOTION.

134. In general the various parts of a machine should move with smoothness and uniformity. Sudden changes in the velocity of machinery are not only injurious to the more delicate parts of the mechanism, but are in many cases incompatible with the nature of the work to be done. Hence it is always desirable, and in many cases indispensable, that the motion of the various parts of machines should be uniform and regular. The contrivances adapted for this purpose are called regulators.

The causes tending to produce irregularity in the motion of machinery are as follows: 1. A variable action in the prime mover; 2. From the relative position of the piece the action of the prime mover may not be transmitted with a uniform efficiency; 3. A variation in the resistances or the work to be done. The object, therefore, of the regulators is to counteract, as far as possible, these causes of irregularity in the motion of machinery.

One of the most beautiful and remarkable achievements of science, is that of making machines *self-acting*. In this respect man seems to have imitated, imperfectly it may be, the creative intelligence everywhere manifested in the mechanism of the universe. This self-acting principle, in many of our manufactories, has been brought to such a degree of perfection, as almost to dispense with human labour and calculation. The work which formerly required the constant attention and manipulation of a skilful mechanic, is now performed with more precision, and at infinitely less cost, by combinations of mechanism requiring only to be at first set in action. Dead matter thus seems, as it were, to be endowed with vitality and intelligence! The steam-engine, for example, supplies itself with water and fuel at the instant they are wanted; adjusts the temperature of its furnace; checks or accelerates, as may be desiderated, the speed of its wheels; and duly regulates the movements of its various parts, without the aid or interference of man. A few of these ingenious contrivances may be readily understood by the student.

THE GOVERNOR.

135. This is one of the most important regulators of machinery. When the speed of the machinery is too great, this contrivance checks the supply of the moving force, and on the contrary, when the speed is too slow, it increases that supply. This simple and beautiful piece of mechanism (see next page) consists of two heavy balls E, E attached to the extremities of the rods *f e* E, which pass through a slit in the vertical axis D D, and turn on the centre *e*, opening and closing like a pair of shears. The links *f h*, having joints at *f* and *h*, connect the two rods *f e* E with a ring *h h* D which slides freely upon the vertical axis D D, to which a rotatory motion is given by means of a belt passing round the pulley *d*. The lever F G H, turning on the centre G, is connected with the sliding piece or ring *h h* D at the extremity F, and has a link H *w* attached to

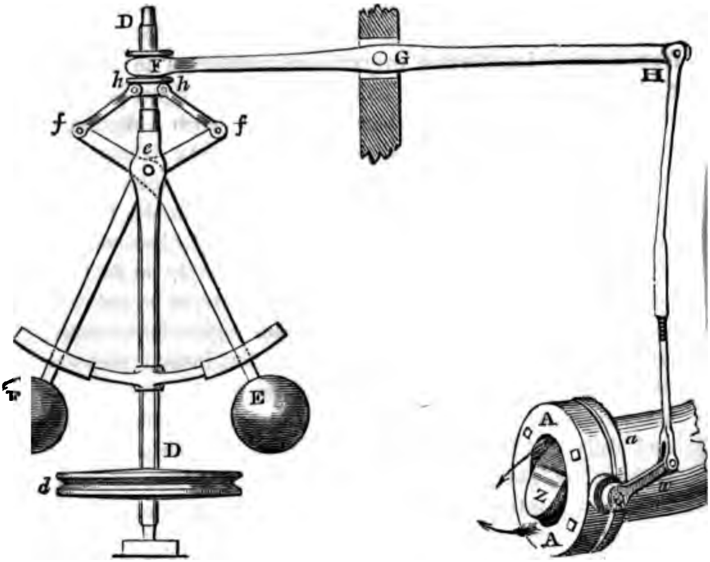


Fig. 118.

the extremity H. The link H *w* turns the axis of the throttle-valve Z which opens and closes the port of the steam pipe A A *a* proceeding from the boiler to the cylinder. Now when the spindle D D revolves with an increasing velocity, the balls E, E fly out from the centre of motion (by the centrifugal force thus generated); the sliding piece or ring *h h* D, with the extremity F of the lever, is drawn downwards, while the extremity H is raised and the axis of *the throttle valve* Z is turned round so as to close the opening of the steam pipe, thereby reducing the supply of the steam. The contrary effect is produced when the velocity of the spindle D D is decreasing, that is, the balls fall towards the axis D D, and the throttle valve Z is turned so as to increase the supply of steam. Hence it appears, that when the speed of the engine passes beyond a certain limit the throttle valve tends to check the supply of the steam, or moving principle, while on the contrary, when the speed of the engine is less than this mean limit, the throttle valve is opened so as to allow a greater quantity of steam to pass through the steam pipe.

Fig. 119. exhibits another form of this mechanism, where

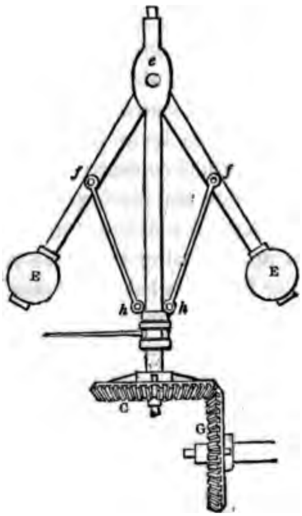


Fig. 119.

the rods *e* E, having a common joint at *e*, are connected with the sliding ring, *h h*, by the links *f h*. In this case a rotatory motion is given to the vertical axis or spindle by means of the bevel-gear C, G.

WATER REGULATOR.

136. In the steam engine it is necessary that the water in the boiler should be constantly maintained at the same level,

so that as the water is being evaporated in the boiler, fresh water should at the same time be admitted to supply the waste thus created. Here A is the boiler; AB a pipe proceeding from the cistern B to supply the boiler with water as it may be required; F is a stone float suspended by the rod FC passing through the stuffing box S; this rod is attached to the extremity C of the lever CF turning upon the fulcrum or centre

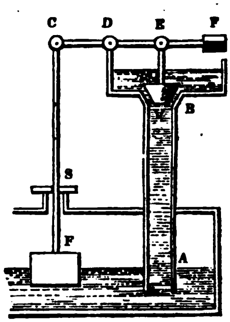


Fig. 120.

D; V is a valve, opening and closing the top of the pipe AB, and attached to the point E of the lever CF; F is a counterpoise which aids in depressing the valve V. Now when the water in the boiler descends below its proper lever, the float F also descends, and by depressing the extremity C of the lever, elevates the valve V and thus allows the water to flow into the boiler as required. On the contrary, as the water rises in the boiler the float F also rises, and by elevating the extremity C of the lever, depresses the valve V and thus stops the flow of water into the boiler; thus a certain mean quantity of water is always maintained in the boiler.

REGULATING DAMPER.

137. The rate at which steam is generated in the boiler should be equal to the rate at which it is consumed in the cylinder; or, what is the same thing, the steam in the boiler should be maintained at a constant pressure. In order to effect this, some connection must be formed between the pressure of the steam in the boiler and the heat of the furnace; since the pressure of the one depends upon the heat of

the other. This has been accomplished by the following contrivance: B A is a tube descending nearly to the bottom of the boiler A; F is a float suspended by a chain P Q D passing over the pulleys P and Q; D is a damper acting as a counterpoise to the float, and opening or closing, as the case may be, the mouth of the flue L, and thereby increasing or decreasing the draft of air through

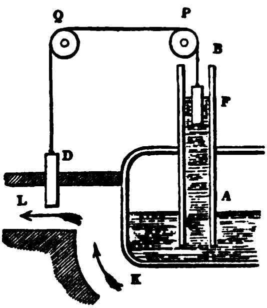


Fig. 121.

the fire K. Now the level F of the water in the tube A B depends upon the pressure of the steam in the boiler A; but the float F rises and falls with the water in the tube A B, and as the float rises the damper D descends and *vice versâ;* so that when the pressure of the steam in the boiler exceeds its proper limit, the water in the tube A B, together with the float F, ascends, and then the damper D descends and closes the mouth of the flue, thereby reducing the intensity of the heat of the furnace, and checking the further generation of steam; on the contrary when the pressure of the steam falls below its proper limit, the water in the tube, with the float, descends, the damper D is raised, and an increase of draft is given to the furnace, which produces a more rapid generation of steam, and consequently with an increase to its pressure.

THE PENDULUM.

It has been ascertained that a pendulum, vibrating in small arcs, will perform each vibration in the same time, even though the lengths of these arcs may differ from each other. The time of vibration depends entirely upon the length of the pendulum. The law in this respect is, that the time of vibration varies as the square root of the length of the pendulum ; thus in our latitude the length of a pendulum to vibrate seconds must be about 39 inches, whereas if it were required to vibrate in two seconds the length must be 4 times 39 inches, and so on to other cases. These important facts were first discovered by the great Galileo. The pendulum is one of the most perfect regulators of machinery; and its application to clocks and chronometers has conferred an incalculable benefit on practical science.

Let QR (see *fig.* 104. p. 60.) be a second pendulum oscillating on its point of suspension Q. Now at each double vibration, one tooth of the crown wheel *e* is carried round, (see Art. 118.), so that if there are 30 teeth in the crown wheel, it will exactly perform one revolution in a minute. The slight strokes given, time after time, to the pallets *o* and *c*, just overcome the resistances of the air and friction tending to destroy the motion of the pendulum.

MACHINES FOR ACCUMULATING WORK. THE FLY WHEEL, ETC.

138. The fly wheel is not only a regulator of motion but it is also an accumulator of motion. It simply consists of a large heavy wheel to which motion is usually given by a crank; thus in *fig.* 182., QQ is the fly wheel, revolving upon the axis P; PN the crank; NM *the connecting rod*, forming the connection between the crank and the extremity of the great beam L.

Here while the extremity of the great beam has a reciprocating circular motion, the fly wheel and its axis have a continuous circular motion. This change in the motion is simply effected by the intervention of the crank and connecting rod.

The fly-wheel may be regarded as a reservoir of motion, in which the redundant motion of the machinery is accumulated when the work to be performed is less than the work applied by the moving power, and from which the machinery derives motion when the work to be performed is greater than the work applied; so that however variable the work to be performed may be, the motion of the machinery is always maintained pretty nearly uniform.

139. The astonishing effect of work accumulated in a mass of matter in motion, is strikingly exhibited in the engine for coining and punching. AB is a lever carrying two heavy

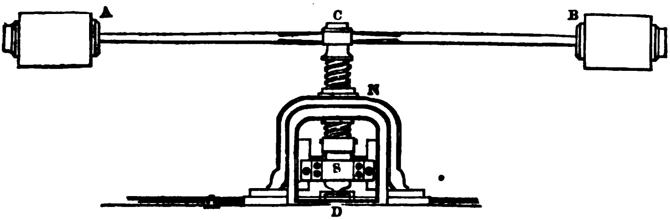


Fig. 122.

pieces of metal A and B at its extremities; this lever turns the screw CS passing through the fixed nut at N and terminating with a punch S (or a die for producing the impression on the coin); D is the metal to be perforated by the punch. Now when a circular motion is given to the masses A and B, work is accumulated in them; the screw CS descends and brings the punch S in contact with the plate D to be perforated; the motion in the masses A and B is thus suddenly stopped, and the whole work accumulated in them at once discharges itself in carrying the punch through the plate. A similar effect is produced when the head of a nail is struck by a hammer.

MECHANISM FOR MODIFYING MOTION.

140. The motions of the parts of machines may be divided into two kinds, viz. *rectilinear*, or in a straight line, and *circular*, or in a circle or some other curve; and each of these motions may again be divided, into *continuous*, or motion

which takes place constantly in the same direction, and *reciprocating*, or back and forward motion. Now the moving and working points of a machine may respectively have any one of these motions, so that there may be a great variety in the combinations of motion subsisting between these two points. Thus, for example, the moving point may have a reciprocating rectilinear motion while the working point may have a reciprocating circular one; and so on to other cases. It would be inexpedient, in a work of this kind, to treat of the various combinations of motion which would arise. However, the following forms will be found to embrace those motions which most frequently occur in machinery.

141. *Continuous circular motions producing motions of the same kind* have already been sufficiently given in the foregoing portion of this work.

TO CHANGE A CONTINUOUS CIRCULAR MOTION INTO A RECIPROCATING RECTILINEAR ONE, AND THE CONVERSE.

142. Various cases of this kind of motion have already been given in Arts. **110, 111.**, &c.; the following are a few additional examples.

The wheel *c* is partially furnished with teeth, which act upon the teeth of the rack *a* cut upon a vertical rod moving between the guides *n* and *m*; *p* is a pestle which falls upon the substance placed in the mortar *o*. Now when a continuous circular motion is given to the wheel *c*, its teeth engage with the teeth of the rack, and thus the rod is raised, but the moment the teeth of the wheel are disengaged, the rod *a* falls; and so on. In this case the wheel moves the rod in only one direction, but it is often necessary that the rod should be moved in both directions by the wheel: the following are examples of this mode of action.

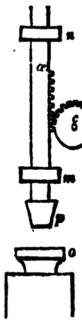


Fig. 123.

143. Here *c* is a wheel partially furnished with teeth, acting

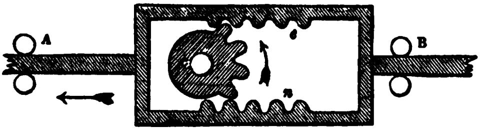


Fig. 124.

on two racks *e* and *n* placed on different sides of it. The teeth in these racks are alternately engaged by the teeth of the wheel, so that the continuous circular motion of the wheel *c* gives a reciprocating motion to the rod or bar A B.

144. In this case there are only three teeth in the wheel *c*, and one tooth, *a* and *b*, on each side of it. In this form of the mechanism, *a* and *b* are called *pallets*, and the teeth on the wheel *c* are called *tappets* or *wipers*.

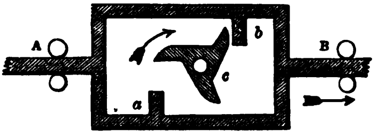


Fig. 125.

145. The wheel *a* in *fig.* 126., is connected with the rod *n d*, capable of moving in the direction of its length only, by the link or connecting rod *m n*, having pins at *m* and *n*; so that when a continuous circular motion is given to the wheel *a*, the rod *n d* performs a rectilinear reciprocating motion.

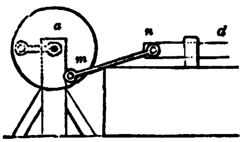


Fig. 126.

146. In *fig.* 127., a cross piece *r s*, with a slit in it, is fixed to the rod *q p*; a pin *c*, fixed on the wheel *a*, moves in this slit, so that while the wheel *a* revolves continuously, the rod *q p*, placed between the guides *m* and *n*, reciprocates in the direction of its length.

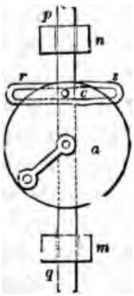


Fig. 127.

147. The following mechanism has been applied to move the pistons of two pumps. N R is a large wheel fixed to the vertical shaft A, and turns with it; A B is a horizontal lever,

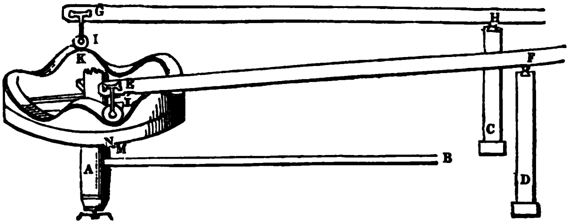


Fig. 128.

for giving a rotatory motion to the shaft A; the crown of the wheel NK is cut into a series of cambs or elevations and depressions, upon which the friction wheels I and L roll; EF and GH are arms of the levers, turning upon the centres F and H, working the two pumps; the friction wheels L and I are fixed to the extremities, E and G, of these two levers. Now when a continuous circular motion is given to the wheel NK, the friction wheels roll over the sinuosities of the cambs, and thus the extremities of the levers are alternately raised and depressed; thereby giving an up and down motion to the pistons of the pumps attached to the opposite extremities of the levers. The arm AB may be turned round by a horse.

148. In *fig.* 129., *fg* is a cross head fixed to the vertical rod *h r*, which has an up and down motion; *p* and *q* are two equal wheels, whose teeth are engaged with each other, turning on axes fixed in the horizontal beam AB; the links *fm* and *gm* connect the cross head *fg* with these wheels; the wheel *p* moves the pinion *c*, turning on the same axis as the fly wheel *s*. Now while the piston rod *h r* makes an up

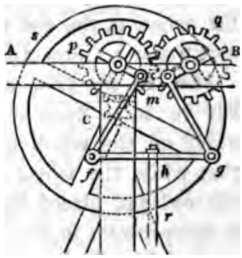


Fig. 129.

and down stroke, the wheels *p* and *q* perform a complete revolution, and the pinion *c*, with the fly wheel, will also be carried round on their axis. The number of teeth in *p* divided by the number in the pinion *c* will give the number of revolutions which the fly wheel *s* must perform while the piston *h r* makes an up and down stroke.

TO CHANGE A RECIPROCATING CIRCULAR MOTION INTO A CONTINUOUS CIRCULAR ONE, AND CONVERSELY.

149. Instances of this kind of motion have already been given in Arts. **29** and **138.**

In *fig.* 130. *c d* is a treadle board, or a board that is moved by the pressure of the foot; the cord *c a e* passes over the pulley *a*, and is attached to the crank *m e* of the wheel *m*. While the extremity *c* of the treadle describes a reciprocating circular motion the wheel *m* revolves continuously.

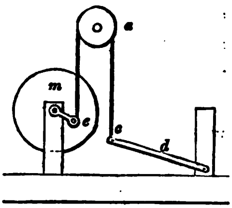


Fig. 130.

150. The crank and connecting rod is a common mode of converting the reciprocating circular motion of the extremity of the great beam into the continuous circular motion of the fly wheel. In *fig.* 182., L is the extremity of the great beam, M the connecting rod, N the crank, and Q the fly wheel.

151. *Sun and Planet Wheel.*—This contrivance was invented by Watt, as a substitute for the crank in converting the reciprocating circular motion of the extremity of the great beam into the continuous circular motion of the fly wheel. The toothed wheel B is fixed to the extremity of the

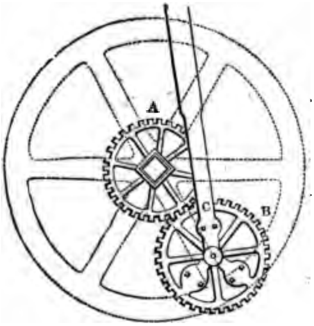


Fig. 131.

connecting rod C D, so as not to be allowed to turn on its centre; A is another toothed wheel fixed to the axis *e* of the fly wheel D; a link connects the centres of the two wheels A and B, and serves to keep them in gear. Now when the great beam has made an up and down stroke, the link *e o*, connecting the centres of the two toothed wheels, will have performed a complete revolution round the centre *e*, exactly as a common crank would do; but as the two wheels A and B are fixed to their respective centres, every portion in the circumference of B will have been brought in contact with the wheel A, which thus receives a continuous circular motion. Assuming the wheels A and B to be equal, then while the connecting rod makes an up and down stroke, or what is the same thing, while the wheel B makes one revolution round the centre *e*, the wheel A, with the fly wheel D, will have performed two revolutions; for in this case every tooth in A will have come twice into contact with the teeth on B.

152. *Eccentric Wheel.*—This important piece of mechanism is usually employed to give motion to the slide valve of the steam engine, where the axis of the fly wheel is always the centre of motion of the eccentric wheel. Here A is the axis of the eccentric wheel, C being the centre of the circle; a hoop JK embraces the eccentric wheel, so as to allow the wheel to revolve freely within the hoop; a frame DFE connects this hoop with the extremity F of the bent lever HGF turning on the fixed centre G. Now when the eccentric wheel turns in the direction of the arrow of the figure, the frame EDF is pushed to the right, and the pin F describes an arc of a circle, in the same direction, on G as a centre; when the lob side of the eccentric has passed the line of the centres of motion A and F, the frame with the pin F is

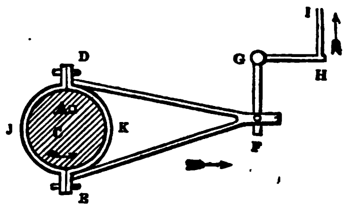


Fig. 132.

then drawn to the left, and so on; so that the continuous circular motion of the eccentric wheel produces a reciprocating circular motion in the pin F. This motion of F gives a reciprocating motion to the rod HI, to which is attached the slide valve of the engine.

153. *The Mangle Motion.*—When a pinion acts upon a spur wheel the axes move in contrary directions; but when the pinion acts upon an annular wheel, as in Art. 63., the axes move in the same direction. A mangle wheel is formed by combining a spur wheel with an annular one. BE is a disk capable of revolving on its centre of motion C; pins B, E, F, forming teeth, are placed concentric with C; these teeth are interrupted from B to F; A is a pinion whose teeth work between the teeth formed by the pins, and is fixed to the end of an axis to which a continuous motion is given; this axis admits of sliding in a horizontal direction from A to D; a short pin projects from the centre of this pinion, and enters a guide groove EFnBA, formed in the disk concentric with the pins or teeth upon it.

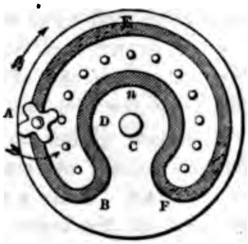


Fig. 133.

Now when the pinion is on the outside of the teeth, the pinion and disk revolve in contrary directions, as shown by the arrows in the cut; but when the last pin at B engages the teeth of the pinion A, the groove guides the pinion from the outside to the inside, and then the disk revolves in the same direction as the pinion, and this will continue until the teeth F is brought to the pinion, which will then be carried to the outside groove, and the disk and pinion will again move in contrary directions; and so on.

154. *Intermittent Motion.*—AB is a lever turning upon the centre of motion A, the moving force applied at B being reciprocating; CE is a click, freely jointed to the lever at C,

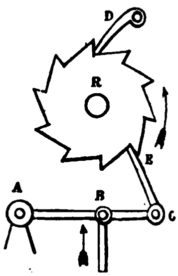


Fig. 134.

and gives motion to the ratchet wheel R; D is a detent for preventing the ratchet recoiling. Now when the extremity B of the lever is moved forward in the direction of the arrow, the click CE acting upon the saw teeth of the ratchet wheel, causes it to move over one or more teeth; and when the extremity B is drawn back in the contrary direction, the point E of the click will slide over the sloping sides of the teeth without giving any motion to the wheel, which will therefore remain at rest during every downward stroke of the lever AB. Thus a reciprocating motion given to the extremity of the lever AB, will produce an intermittent circular motion in the axis R.

TO CHANGE A RECIPROCATING CIRCULAR MOTION INTO A RECIPROCATING RECTILINEAR ONE, AND CONVERSELY.

155. The rack and pinion is an example of this kind of motion. See *figs.* 64, 65, and 66., where, in *fig.* 64., an oscillating motion in the wheel will produce a reciprocating rectilinear motion in the rack A; and in *figs.* 65. and 66. a reciprocating circular motion given to the extremity P of the handle will produce a reciprocating rectilinear motion in the rack S.

156. In Newcomen's steam engine, see *fig.* 182., the piston rod P is kept moving in a vertical line, by means of a chain, attached to the top of the piston rod, coiling round a sector *a b* formed upon the head of the great beam, and fixed to it at the upper part *b*. The arc *a b* must obviously be described on *e* as a centre, *e* being the axis of the great beam. Now as the beam oscillates, the line in which the *piston* rod moves will always form a tangent to the circular ad *a b*. In this case the single chain *a b* only exerts a lling force, so that this mechanism can only give motion the beam in a descending stroke of the piston.

157. By employing two chains the piston is made to act on the beam in both directions of the oke. One of the chains *e b* is attached he top of the arch-head and to the lower t of the rod *g n*, whereas the other in *e g* connects the lower end of the h-head with the upper part *g* of the rod. ıen the rod *g n* is descending the chain acts upon the beam, at the time the in *e g* is being coiled upon the arch-d, whereas when the rod *g n* is ascend- the chain *e g* in its turn acts upon the beam; and so on.

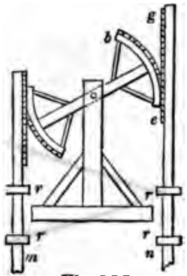


Fig. 135.

.58. If an oscillating motion be en to the toothed wheel *a*, the thed wheel *b* will oscillate in an op-ite direction, so that both wheels, ing upon their respective racks, will d to give a reciprocating rectilinear tion to the frame *c d*.

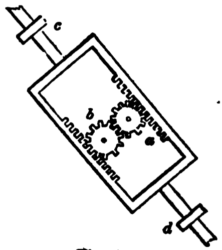


Fig. 136.

.59. *The zigzag*, a common toy, is amiliar example of this kind of mo-ı. By compressing and extending the arms *a* and *b*, a id alternating rectilinear motion is en to the point D.

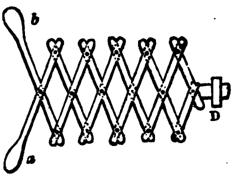


Fig. 137.

160. *Watt's parallel Motion.*—The ect of this beautiful contrivance is convert the reciprocating circular tion of the extremity of the great m into the reciprocating rectilinear tion of the piston rod.

Let AB and CD be two equal rods, connected by the link , moving on their respective centres of motion A and C; he middle point of the link DB. Let C *d e b* A be another

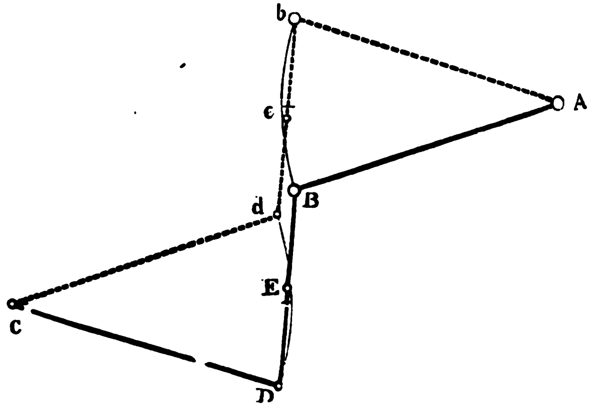


Fig. 138.

position of the rods, then the middle point E or *e* of the link will have nearly moved in a vertical right line. For while, by this motion, the extremity B of the link is carried to the left, the extremity D is carried to the right, and *vice versâ;* so that the middle point E of the link thus nearly moves in a vertical line.

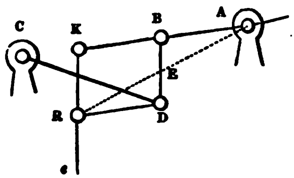


Fig. 139.

Let AK represent one half of the great beam, turning on the centre A; KBDR link work in the form of a parallelogram, having BK equal to AB; CD a rod, called *the radius rod*, turning on the fixed centre C. Now the rods AB, DC will move in precisely the same manner as in the preceding figure, and therefore the point E, in the middle of the link DB, will very nearly describe a vertical line. But since the triangles ARK and AEB are similar, and as AK is the double of AB, the line AR will be the double of AE; that is, the *point* R will always be at double the distance from A that the oint E is ; and therefore the path described by R will be the ame as the path described by E ; therefore, if the point E noves in a vertical line, the point R will also move in a vertical line. The piston rod is attached to the point R, and he piston rod of the air pump to the point E ; so that both f these rods will be moved in a vertical line.*

Fig. 140. represents the form given to the parallel motion n the common double-acting steam engine, where CB is one alf of the great beam; BRHE the link work forming a

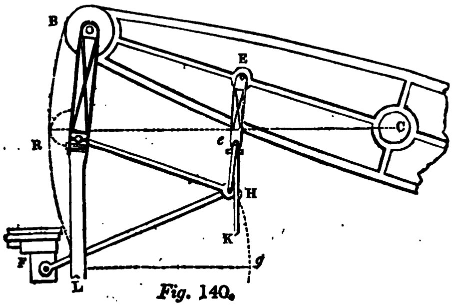


Fig. 140.

arallelogram; FH the radius rod; RL the piston rod; *e*K e rod of the air pump. The links forming the parallel otion are all double.

The actual path described by the points R and *e* is a curve ving the shape of an eight figure, but that portion of the irve lying within the extent of the stroke of the piston rod most exactly coincides with a straight line.

161. *White's Parallel Motion.* — In *fig.* 141. A is a large heel having teeth cut on its inner circumference, fixed to a ame FF ; DCE is the piston rod, in a line with the vertical ameter of the wheel A, and attached freely to the crank n E, fixed on the circumference of the toothed wheel *g*, in

* Mr. Hann, of King's College, has given, in his work on the steam gine, a simple method for constructing parallel motion.

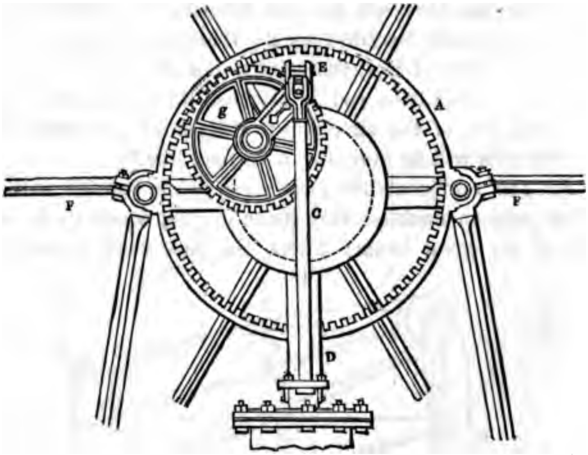


Fig. 141.

gear with the teeth of A. Now as the piston rod moves up and down, the wheel *g* rolls within A, ascending on the one side and descending on the other. It is well known that the point E will in general describe a curve called the hypocycloid; but when the diameter of the rolling wheel is equal to the radius of the fixed one, then the curve becomes a straight line. Hence, when the dimensions of the wheels have this proportion, the piston rod DCE always moves in a vertical line.

ON MACHINES.

CHAP. VIII.

VARIOUS KINDS OF MACHINERY.

Machine for Raising Water by means of Buckets from Deep Wells.

162. AF is a vertical shaft, turning upon the pivots *e* and *c*, to which motion is given by means of the levers G, G, &c.;

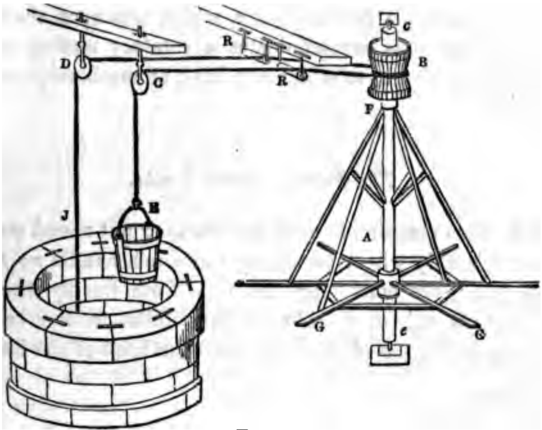


Fig. 142.

the axle B is fixed to the upper end of this shaft and turns with it; a continuous rope ECRBRDJ coils round this axle, going over the rollers R, R and the pulleys C, D; each extremity of this rope carries a bucket E, so that while one bucket is ascending the other is descending.

Horse Mill.

163. A is a vertical shaft, turning on the pivots *n* and *r*,

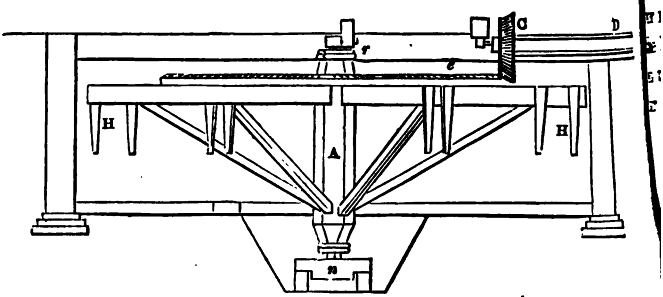


Fig. 143.

and moved by horse power applied to the horse wheel HH′; this shaft carries a bevel wheel *e*, which acts upon the bevel wheel C, and thus communicates a rotatory motion to the horizontal shaft CD, to which any kind of machinery may be attached.

The Potter's Hand Lathe.

164. This machine is used for blocking out round pottery ware: *c* is a fly wheel turned by the winch handle *r*; *f* is a guide pulley for conveying the rope from the fly wheel to the vertical axle *d*, thereby giving motion to the vertical axis *b a*, to the top of which is fixed the head of the lathe *a*,

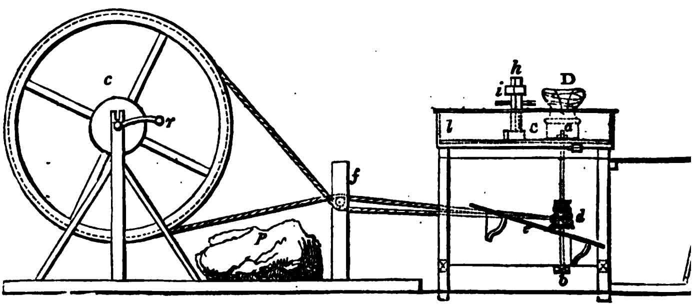


Fig. 144.

for receiving the object D to be turned; C is the table; *k* is the bench upon which the workman sits astride, with his feet on the treadle *e*; *i h* is an instrument with a slide nut, &c. for measuring or gauging the objects on the block *a*.

The Crab.

165. This portable machine is much used in raising build-

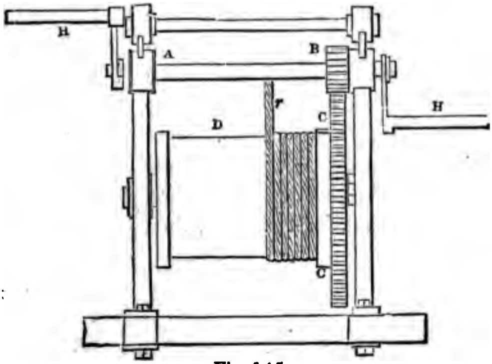


Fig. 145.

ing materials. H, H are two handles which turn the axis A B, upon which is fixed the pinion B, driving the spur wheel C C, fixed to the same axis as the drum or axle D, round which the rope *r* coils (see Art. 48.). The rope *r* passes up to a pulley fixed to the top of *a gin* or *pair of shear legs*, for the purpose of raising heavy stones, &c.

The Hand Jack.

166. This machine is also much used in building for raising, over a short distance, large blocks of stone or timber. H is the handle, which gives motion to the pinion *p*; this pinion drives the spur wheel K, and its pinion *c* acting upon the teeth of the rack D G; D is a detent sustaining the rack as it is elevated; F is a double claw for laying hold of the load to be raised.

Let the number of teeth in $c=4$,
in $K=40$,
in $p=5$,

then in order that the rack should be raised through the distance between its teeth, the wheel K must move round ten teeth, and the pinion p with its handle must make two revolutions, that is to say, while the rack ascends the space between two of its teeth, the handle must make two entire revolutions. Now if the handle sweep over a circumference of 100 inches, and the distance between the teeth of the rack be $1\frac{1}{4}$ inches, then we have

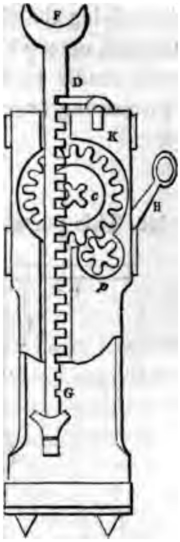


Fig. 146.

$$\therefore \text{advantage gained} = \frac{\text{velo. power}}{\text{velo. resistance}}$$
$$= \frac{2 \times 100}{1\frac{1}{4}} = 160.$$

The Gib Crane.

167. DO is a vertical beam, resting as well as turning upon a pivot at its under end, and supported in its upright position by stays in the floor with rollers attached to them; KB is an arm projecting from the beam DO, having a pulley B at its

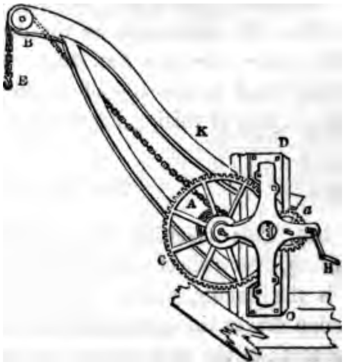


Fig. 147.

ty; the axes of the wheel work are supported by
t-iron crosses bolted on each side of the vertical
H, the winch or handle, turns a pinion fixed on its
his pinion turns the spur wheel *a*, which carries a
on its axis; then this latter pinion turns the large
with its barrel or axle A, round which the chain is
this chain passes over the pulley B, and has a hook
xtremity for laying hold of the weight to be raised.
rrel A has a racket wheel and detent. As the gib
of being turned round in any direction, a weight
rom one side of it may be turned round and let down
pposite side, or at any part within the sweep of the gib.
This figure represents the manner in which cranes

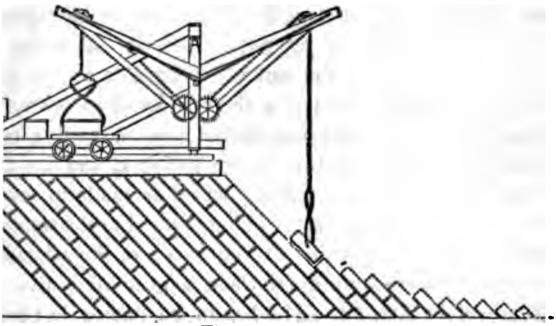


Fig. 148.

quently employed in erecting large buildings. The
he crane is shown in two positions: in one position
ne is being elevated, and in the other it is being
d upon its bed.

The Foot Lathe.

A *a* is an axis called a mandrill, revolving on two
pports, and carrying a pulley E; B S is an iron frame,

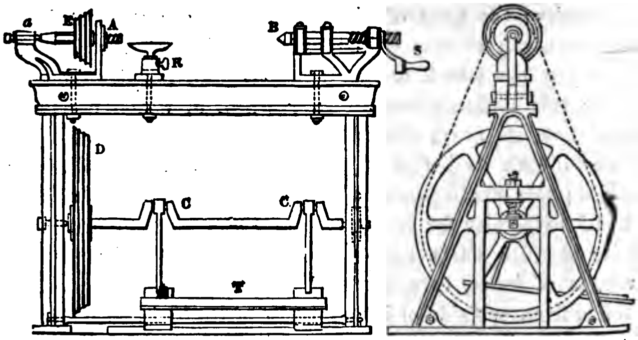


Fig. 149.

called a puppet, carrying a pointed screw SB for adjusting the space AB to the length of the bar to be turned; the whole of this frame or puppet admits of being moved longitudinally, when the nut which fixes it to the frame of the lathe is unscrewed; R is the rest for the workman's tool, which also admits of being shifted longitudinally; D is a fly wheel which gives motion to the pulley E, and its axis *a*A, by means of a strap; this fly wheel is made to revolve by the cranks C, C, the pressure being applied to the treadle T. In order to vary the velocity of the axis A *a*, the wheels E and D have grooves cut upon their edges, after the method explained in Art. 53. The bar to be turned is placed between the pivot B and the mandrill A, so that the bar revolves with the pivot A *a*.

Self-acting Slide Rest.

170. This contrivance exhibits a principle which is now employed in almost every kind of machinery. CD is the bar to be turned, revolving between the pivot B and mandrill; C*e* is a hoop of iron tightly wrapped round the bar, and acting at each successive revolution on the teeth of the wheel *n*, which therefore revolves through the space of one tooth at each turn of the bar; this wheel carries a screw which,

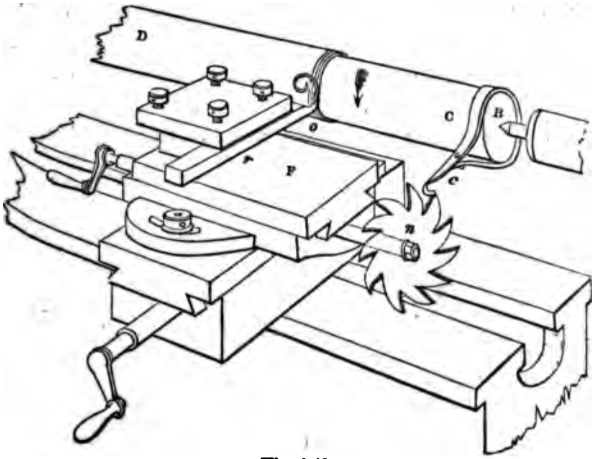


Fig. 150.

when *n* revolves, slowly moves the frame F with the working tooth *r o* in a longitudinal direction, so that the point *o* of the cutting tool shaves off the redundant metal from end to end, and thus forms a perfect cylinder, without any aid or interference of the workman. This is a useful application of an intermittent motion.

Machines for cutting Screws.

171. In order to form a screw on a cylinder, the cutting point must trace a spiral course upon its surface. The point *e* may be made to trace a spiral upon the cylinder C by the following mechanism. The winch H turns two toothed wheels on the same axis; the wheel nearest the winch acts upon the rack A B carrying the point *e*; while the bevel wheel D turns the bevel wheel E revolving on the same axis as the cylinder C.

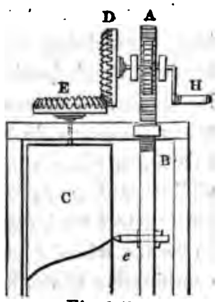


Fig. 151.

Now when the winch H is turned round, so as to cause the rack to ascend, then the cylinder C will, at the same time, be turned on its axis: so that the path of the point *e* on the cylinder will be a spiral.

172. This figure represents a self-acting machine for

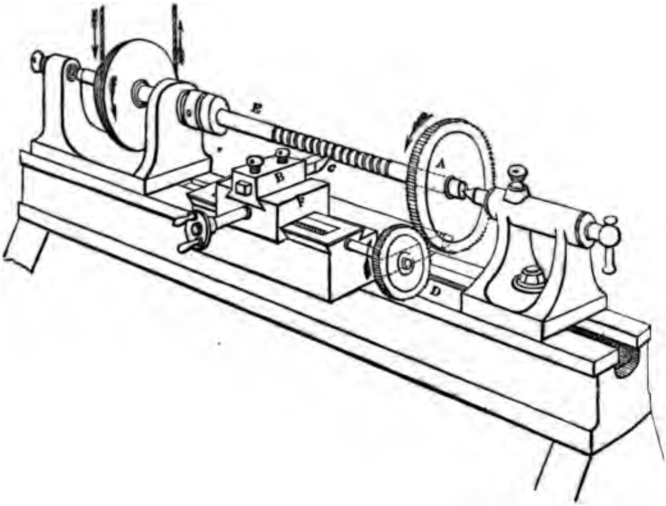


Fig. 152.

cutting screws. AE is the cylinder on which the screw is to be cut, revolving with the mandrill E of the lathe; A is a toothed wheel fixed to the cylinder AE, and revolving with it; this wheel drives a smaller wheel D, which carries a long screw revolving in bearings fixed to the frame of the lathe; this screw gives a longitudinal motion to a nut carrying the sliding table or *saddle* F, upon which is securely clamped the cutting tool B*c* intended to form the screw. It is customary to fix the wheel A on the axis of the mandrill. Moreover a combination of toothed wheels may be used in the place of D, so as to give any required relative longitudinal velocity to the saddle.

The Hand Drill.

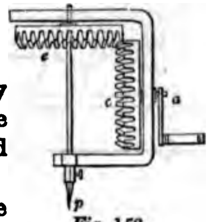


Fig. 153.

173. In *fig.* 153. a simple rotatory otion is supposed to be given to the ill *p*, by means of the winch *a* and vel gear *c* and *e*.

174. In *fig.* 154. a frame supports the right spindle B p which carries the drill ; the winch H turns the fly wheel F revolving on the axis

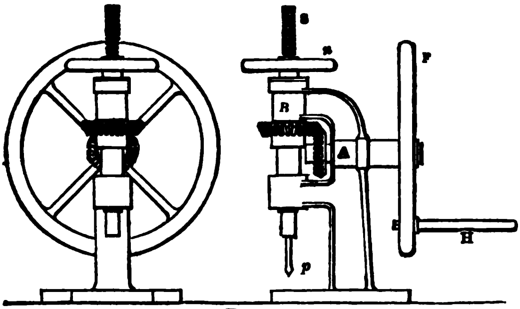


Fig. 154.

the rotation in the horizontal axis A is communicated to vertical spindle B by means of the two bevel wheels ced at right angles to each other; the top of the drill has screw S cut upon it, with a handle *n*. Now while the indle B is revolving, a slight motion is given to the handle which causes the drill to descend and its point to perate the plate.

Shears for cutting Metal.

175. The eccentric wheel A, revolving on its centre of tion *c*, acts upon the friction roller *e*, attached to the exmity of the lever E D *e* oscillating upon its centre D; E, E

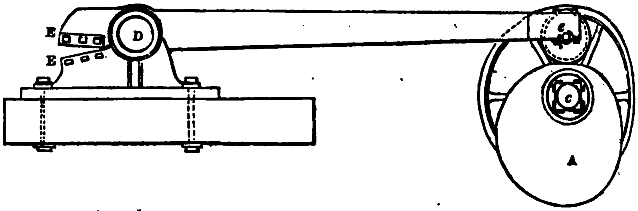


Fig. 155.

are the edges of the shears for cutting the metal; the friction wheel *e* has a groove in its edge for receiving the edge of the eccentric wheel A, and the weight of the arm D*e* keeps the wheel *e* always in contact with A. In the position shown in the figure, the metal to be cut is placed between the edges of the shears, and as the wheel A revolves, the extremity *e* of the lever is raised, and thus the edges E, E of the shears are closed upon the metal; and so on.

The Dredging Machine.

176. This machine is used for increasing the depth of the channel of navigable rivers, by removing the sand and mud which time after time accumulate in them.

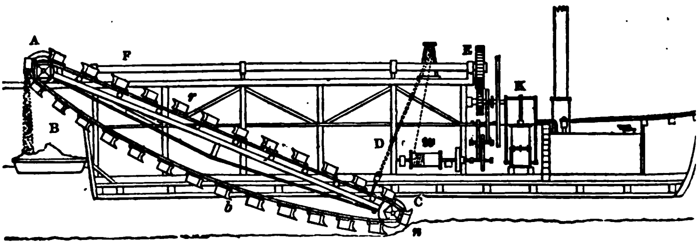


Fig. 156.

A*r*C*nb* are a series of buckets attached to the alternate links of an endless chain going round the square revolving axles A and C, similar to a chain pump, (see Art. 89.); so that while the full buckets are ascending on the upper side *r*, the empty ones are descending on the under side *b*; the outer edges of the buckets are made of a pointed shape, so as to pierce the sand or gravel in the bed *n* of the river; they are are also perforated so as to allow the water to run out of them. As the buckets pass round the square axle A, they are turned upside down, and thus the sand, or other materials raised from the bed of the river, is allowed to fall into the boat B. The depth to which the under end C of the dredge is sunk, is adjusted by the chain D and windlass *w*. The toothed wheel E, revolving on the horizontal shaft EF, is turned by the machinery connected with the steam engine K; then this shaft gives a rotatory motion to the axle A by means of bevel-gear.

The Pile Engine.

177. This engine is used for driving piles of wood into

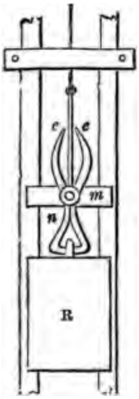


Fig. 157.

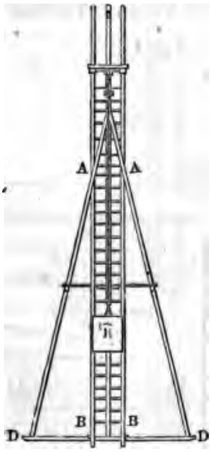


Fig. 158.

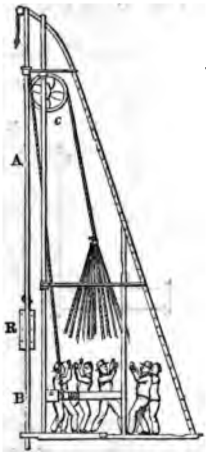


Fig. 159.

the ground for the purpose of securing the foundations of buildings, the piers of bridges, &c. In *figs.* 157. and 158., R a heavy piece of metal, called *the ram*, which by falling up the head of the pile drives it into the ground; the ram elevated by means of a cord going over the pulley *c*; *e* is a pair of nippers, attached to the extremity of the co which lay hold of the hoop on the top of the ram; *m* is slide piece, to which the nippers are fixed; now when t ram arrives at the top of the frame, the forked extremity of the nippers becomes compressed between the sides of t angle formed by the timbers AD, AD, and thus the nippers *n* open and allow the ram to fall; when the nippers a allowed to fall, they close upon the hoop of the ram, a thus the ram is prepared for another lift. The ram may raised by *a crab*, or by human power applied to a series ropes as shown in *fig.* 159.

The Hand Mill for grinding Corn.

178. Here C is a face wheel, revolving on its bearings R, :

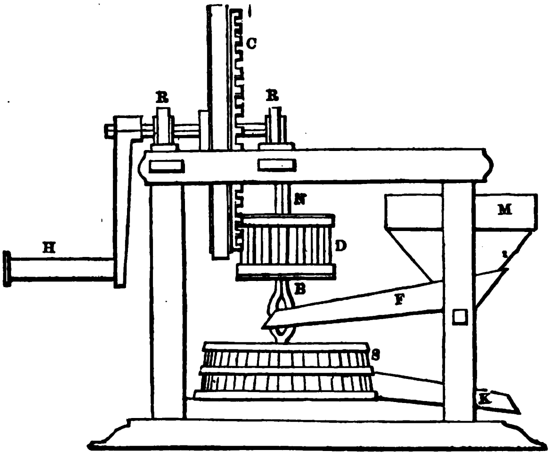


Fig. 160.

and turned by the winch H; the teeth of the wheel C engage the staves of the trundle D revolving on the vertical axis NB; the upper or revolving stone of the mill is fixed to this axis, and revolves with it; M is the hopper for receiving the corn to be ground, which is conveyed to mill-stones by the spout F; S is a case which encloses the stones; and the spout S, proceeding from the under part of this case, carries away the flour as it is being ground. The corn falls from F upon the under stone through a hole cut in the centre of the upper one; and the grain, as it is being crushed between the stones, is carried off by the centrifugal motion generated by the rotation of the upper stone.

The Saw Mill.

179. *Fig.* 161. is a representation of the mechanism employed in this machine. W is a fly wheel, driven by an engine, and having fixed on its axis a crank G and an eccentric F; GH is a link connecting the crank with the saw frame HS, which moves between vertical guides; the eccentric F communicates an oscillating motion to lever AC on its fixed centre A; the click CE then gives an intermittent motion to the ratchet and its pinion R, as described in Art. 154.; this pinion, acting on the rack *kg*, advances the wood-carriage towards the saw with the same intermittent motion. The crank and eccentric are so adjusted, that when the saw-frame is descending, the timber is at the same time advancing towards the saw to receive its cut; and when the saw-frame is *ascending, the timber* is at rest.

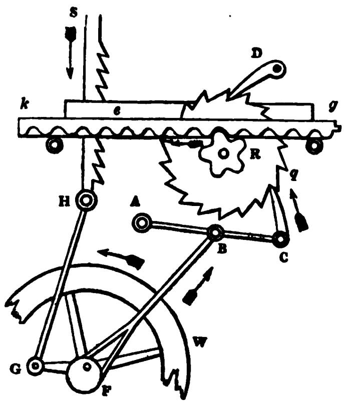


Fig. 161.

Spinning Machines.

180. The rollers C receive the fine rovings of flax from

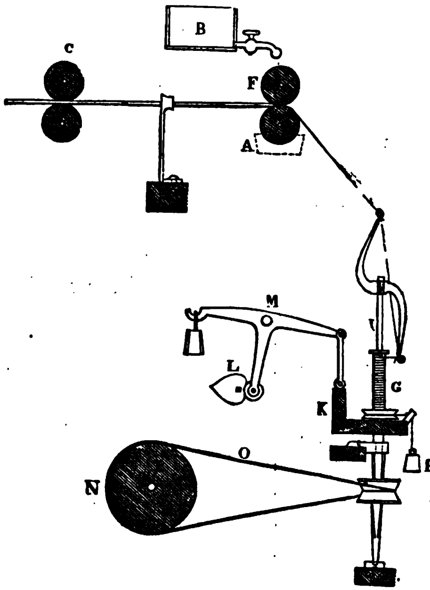


Fig. 162.

bobbins; F is a pair of drawing rollers, which are moistened by water trickling upon them from a vessel B, or by having the lower roller partially immersed in the water contained in the vessel A. The thread, as it passes from the drawing rollers, is twisted by the spindle and flyer, and wound up on the bobbin G; the motion of this bobbin is retarded by a weight H, hanging by a cord going round a pulley groove formed on the end of the bobbin: the friction of this cord may be increased or decreased by altering the leverage of the weight.

that the bobbin may have any requisite speed for winding the yarn as it is twisted. The bobbin G has also a motion and down the spindle I, in order to spread the yarn equally r the barrel of the bobbin. This motion is effected in the owing manner: the camb or double eccentric L turns vly on its axis, and causes the balance lever M to oscillate vly on its axis M, thereby giving a slow up and down tion to the bobbin-rail K with its range of bobbins. N is ross section of a long drum, extending the whole length of frame, and giving a rotatory motion to all the row of ndles, by means of an endless cord O passing over a pulley d to each spindle. This drum, by the intervention of ds, &c., also gives motion to the rollers C and F, as well o the eccentric L by the intervention of an endless screw.

The Smoke Jack.

81. This well-known machine is used in the kitchen for

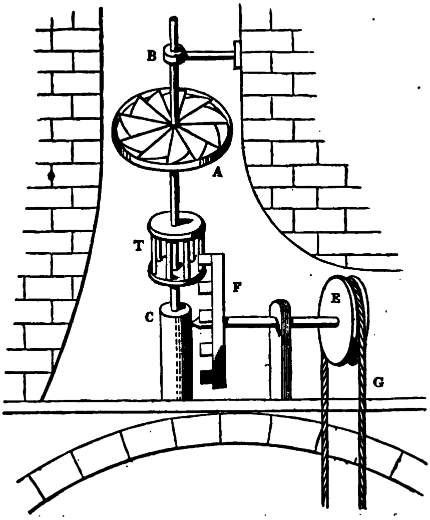


Fig. 163.

turning a spit. The rarified air and smoke, ascending the chimney, strike against the inclined sails of the horizontal wheel A, and cause it to revolve upon its vertical axis CB; T is a trundle fixed to this axis, giving motion to the face wheel F revolving on the horizontal axis FE, which carries the wheel E round, over which passes the chain G, giving a rotatory motion to the spit.

The Clock.

182. In this figure W represents the weight, giving motion to the wheel-work; QP the pendulum, regulating the motion; *h* the hour hand; *m* the minute hand; *s* the second hand; LB and KD side frames in which the various axes turn.

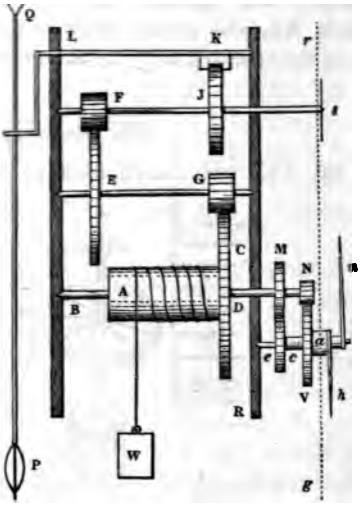


Fig. 164.

The weight W is suspended by a cord, which coils round the barrel A moving on its axis or *arbor* BD; this axis carries the toothed wheel C, which drives the pinion G, fixed to the second axis or arbor GE, which also carries a toothed wheel E; this wheel drives the pinion F, fixed on the third arbor FJ, and upon this arbor is fixed the escapement wheel J (see Arts. **118.**, **119.**, and **137.**,); the pallets of this escapement wheel are fixed to an axis or verge LK, which vibrates with the pendulum QP.

Let the wheel J contain 30 teeth, then if the pendulum vibrates seconds, this wheel (see p. 85.) will revolve in one minute, and the pointer *s* will perform a rotation in this time. Now the number of teeth, in the various wheels and pinions, is commonly taken so that the barrel A may perform a revolution in one hour. Thus, for example, if F have 8 teeth, E 48, G 5, and C 50, then the barrel A will complete a revolution in one hour, which may be verified as follows. While C makes one revolution G makes 10; while E makes one revolution F makes 6; and therefore while E makes 10 revolutions F must make 10 times 6, or 60 revolutions; thus while A makes one revolution F makes 60: but F makes one revolution in a minute, and therefore it must take an hour to perform 60 revolutions; hence A makes one revolution every hour.

The train of wheels just described has solely a relation to the regulator or pendulum, but the train about to be described gives motion to the hour and minute hands.

The axis BD, projecting through the plate KD, carries the toothed wheels M and N. To the plate KR is fixed a pin or *stud e*, on which freely revolves a tube *c*, carrying a toothed wheel at one extremity and the arm *m* of the minute hand at the other; on this tube another but shorter tube *a* revolves freely, carrying the toothed wheel V at one extremity and the hour hand *h* at the other. The two wheels V and *c* just described are acted upon by the wheels M and N (see Art. 86.). Now as M revolves in an hour, and as the wheel *c* of the minute hand must also revolve in an hour, so therefore the wheels M and *c* must contain the same number of teeth. Again, as the wheel V of the hour hand must take 12 hours to perform a revolution, and as N revolves in 1 hour, so therefore the wheel V must have 12 times as many teeth as N.

CHAP. IX.

PUMPS AND OTHER HYDRAULIC ENGINES.

The Common Pump.

183. The accompanying figure represents a section of the common suction pump. A C is a cylinder or barrel, in which a piston P is moved up and down by means of a piston rod R, attached to the extremity of the lever, R H, of the first kind. In the piston is a valve *v* lifting *upwards;* and at the bottom of the barrel is another valve V, also lifting *upwards.* A B is a pipe, passing from the bottom of the barrel into the well from which the water is to be raised.

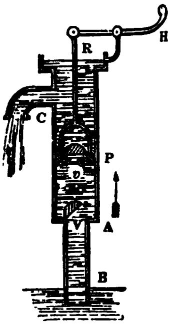


Fig. 165.

The first effect of the motion of the piston is to clear the barrel and pipe of air; at the first upward stroke of the piston, the air, in the pipe A B, expands and enters the barrel, and being thus rarified, exerts less pressure upon the water in the pipe; the consequence is, that the pressure of the external air forces a portion of water into the pipe. Now in the downward stroke of the piston, the valve V closes, while *v* opens and allows the air in the barrel to escape, so that there is now a much less quantity of air in the pipe than there was at first; at the second upward stroke, therefore, the air in the pipe is still further rarified, and thus an additional quantity of water is raised in the pipe by the pressure of the external air; proceeding in this manner, after a few strokes, the water is raised into the barrel, and then another kind of action takes place.

In a downward stroke of the piston, it plunges amongst the water in the barrel of the pump; the valve V closes, and the valve *v* opens, and allows the water to pass to the upper side of the piston. In an upward stroke the valve *v* closes, and the valve V opens, and, by the pressure of the atmosphere, the water follows the piston in its ascent, whereas the water above the piston is pushed before it, and thus the fluid is discharged in a stream at the mouth, C, of the pump; and so on to any number of strokes.

If a perfect vacuum were formed by the piston as it ascends, the water would be raised, on an average, to the height of 34 feet above the level of the water in the well, which is the height of a column of water calculated to balance the average pressure of the atmosphere.

The Common Forcing Pump.

184. This pump raises water from the well into the barrel, on the principle of the suction pump just described, and then the pressure of the piston on the water elevates it to any height that may be required.

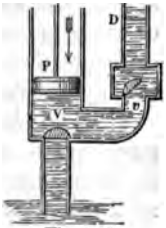


Fig. 166.

Here P is a solid piston working up and down in a barrel; V a valve, lifting upwards, placed at the top of the pipe descending into the well; *v* a valve, also lifting upwards, placed in a pipe D, which conveys the water to the cistern.

In a descending stroke of the piston, the valve V closes and the valve *v* opens, and the water, being pressed before the piston, is forced up the pipe D to the higher level required; on the contrary, in an ascending stroke, the valve *v* closes by the pressure of the external air and the water in the pipe D; the valve V opens, and the water rises into the barrel of the pump by the pressure of the atmosphere on the water in the well; and so on to any number of strokes.

The Forcing Pump with an Air Chamber.

185. This engine merely differs from the preceding one by having an air chamber *e c v* connected with the vertical pipe D. This air chamber is a closed vessel, having the pipe D descending into it, and a valve *v* opening and closing its communication with the barrel of the pump. When the piston P descends, the water is forced, through the valve *v*, into the air chamber, so that as soon as the water rises above the lower orifice of the pipe D, the air in the upper part of the chamber is contracted or compressed; and this compression of the air causes it to exert a continuous pressure upon the surface of the water in the chamber, which forces the fluid up the pipe D, and thus a constant discharge into the cistern is sustained. In the common forcing pump the water is only discharged at each downward stroke of the piston, whereas, in the present case, the pressure of the air in the chamber sustains the discharge through the vertical pipe D, during the intervals taken up by the upward strokes of the piston.

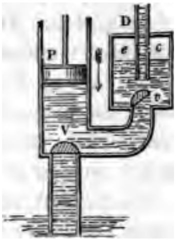


Fig. 167.

The great defect of this engine is as follows:—after the pump has been some time in action the air in the chamber becomes absorbed by the water passing through it, so that at length it is found that nearly all the air at first in the chamber has passed away with the water discharged by the pump.

Double-acting Pump.

186. This pump is designed to remedy the defect of the preceding one. It is simply a double-acting forcing pump, similar in its construction to that described in Art. **184**. P is a solid piston which moves up and down in a cylinder; the rod of this piston passes through a stuffing box at S for the purpose of keeping the cylinder air tight. On the opposite sides of the cylinder are two pipes A B and C D; where A B descends into the well, and C D conveys the water to the reservoir. There are four valves, *a*, *b*, *e*, *c*, opening and closing,

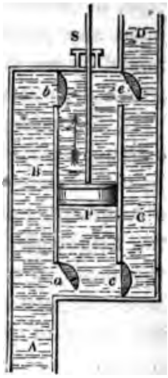


Fig. 168.

case may be, the communication of pes with the cylinder. These valves in the same direction, that is to the Suppose the cylinder and pipes filled ater, then, in an upward stroke of the the valves *a* and *e* are opened, and *c* are closed; the water is forced by on through the valve *e* and then up tical pipe CD; at the same time the by the atmospheric pressure, rises up e A, and opening the valve *a* follows on in its ascent: on the contrary, when ton descends, the valves *a* and *e* are and *c* and *b* are opened; the water forced, through the valve *c*, up the vertical pipe CD, water from the well enters the cylinder through the and follows the piston in its descent; and so on to nber of strokes.

The Fire Engine.

This engine is simply a combination of two forcing having a common air r H, and the same suc- e F descending to the ntended to supply the (see Art. 184.). The B, turning on its centre on K, works the two C and D; so that while is descending the other ding, thereby keeping up uous flow of water into chamber H. A flexible L, of leather, called *a* attached to the discharge

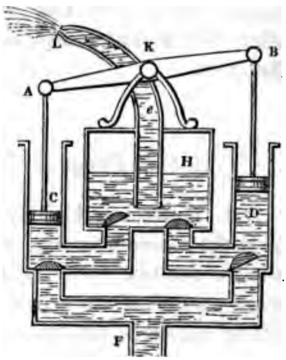


Fig. 169.

pipe, to enable the engine-man to direct the stream of water upon any particular spot. The degree of compression attained by the air in the chamber, regulates the velocity with which the water is projected from the nozzle L of the hose.

If, for example, the air be compressed to one half its original bulk, then it will act upon the surface of the water in the chamber with a pressure equivalent to that of the atmosphere, and the water would be raised in the pipe *e* to the height of about 34 feet, or it would be projected from the nozzle L with a velocity equal to that which a body would acquire in falling freely, by the force of gravity, from this height.

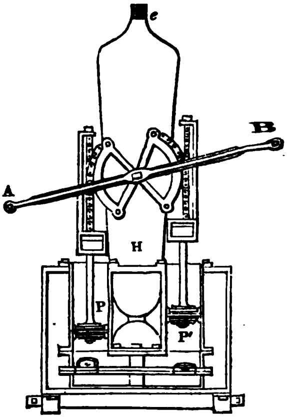


Fig. 170.

Fig. 170. shows the manner in which the fire engine is sometimes worked. Here H is the air chamber, A, B the handles by which the men work the pumps, and *e* the part of the discharge pipe to which the hose is attached.

The pistons P and P′ are moved up and down by double chains attached to two sectors, after the manner explained in Art. 157.

A Ship Pump working with Parallel Motion.

188. Water is raised by this engine in the same manner as in the common forcing pump, with an air chamber. Here S and S′ are two cylinders in which the solid pistons P and P′ work; D and D′ are valves lifting upwards; V and V′ valves lifting outwards into the air chamber A; K is a pipe first passing laterally and then downwards into the water which is to be raised; B G, G E F, F C, the rods forming the parallel motion

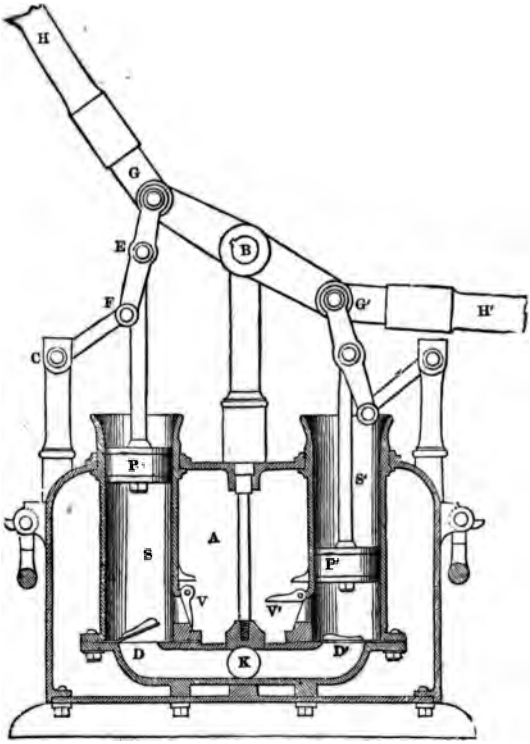


Fig. 171.

explained in Art. 160., CF being the radius rod, FG the ık to which is attached the piston rod PE, and GB one half the beam GG′ oscillating on its axis B; H, H′ are levers, by ıich an up and down motion is given to the beam; trans-rse bars are fixed to these levers, so as to allow a sufficient mber of men to work on each side.

The Chain Pump.

189. This engine consists of a continuous chain ABC, to

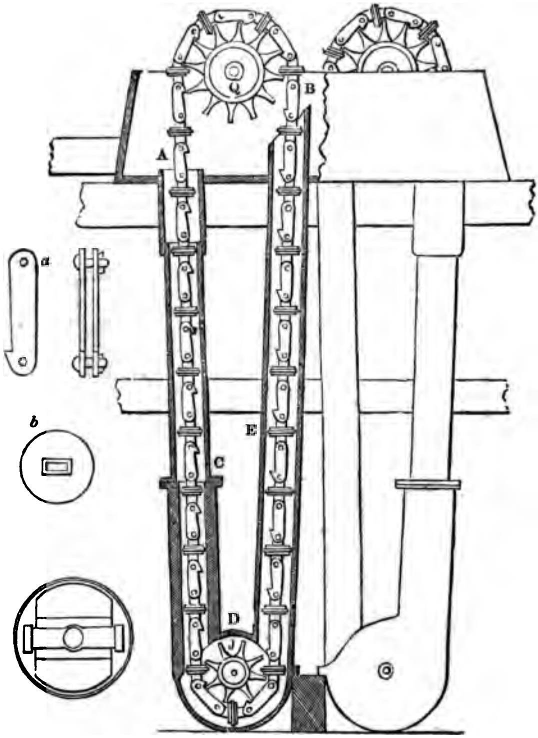


Fig. 172.

which are attached a series of pistons or buckets for raising the water. This chain passes downwards through the wooden tube E, and returns upwards through C, extending over two *sprocket* wheels Q and J. The arms or teeth of the upper wheel Q, acting upon the notches or teeth cut upon the links of the chain, put the chain of pistons or buckets in motion. The lower portion CD of the ascending tube is lined with a brass barrel, in which the pistons or buckets are fitted; so that whilst they are ascending through this barrel, the water is

up and discharged at the top A of the tube. The
Q is turned by a winch; *a* shows the shape of the links
ıg the chain; *b* the section of the pistons or buckets.

A Pump wrought by a double Crank.

. This figure exhibits a method of working two com-

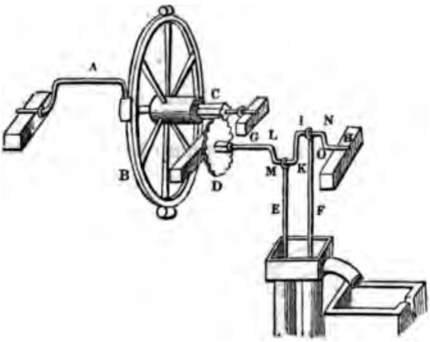


Fig. 173.

ıumps by means of cranks, so as to maintain a con-
s discharge of water. The power is applied to the
A, giving a rotatory motion to the fly wheel B and the
C fixed on the same axis; the pinion C gives motion
spur wheel D, turning on its axis GH; this axis is bent
ıe form of two cranks LMK, INO; to these cranks are
ed the piston rods E and F of the two pumps.
blem. Let the circumference described by the winch
et; the number of teeth in the pinion C and wheel D
tively $=6$ and 30; the height to which the water is
$=20$ ft.; and the quantity of water discharged at each
stroke of the pistons, or, what is the same thing, at
evolution of the crank-axis $=2$ cubic feet; it is re-
. to find the pressure, P lbs., which must be applied to
nch, the modulus of pumps being $\frac{2}{3}$.

Here while the crank-axis makes one revolution the winch makes 5;

∴ the space moved over by the power P during a double stroke of the pistons $=6\times5=30$ ft.;

∴ effective work performed by P in this space $=30\times P\times\frac{2}{3}$;

and work in pumping the water $=2\times62\cdot5\times20$;

$$\therefore\ 30\times P\times\tfrac{2}{3}=2\times62\cdot5\times20;$$

$$\therefore\ P=125 \text{ lbs.}$$

Pumps for raising Water from Dykes.

191. Here D and E are two pump barrels communicating

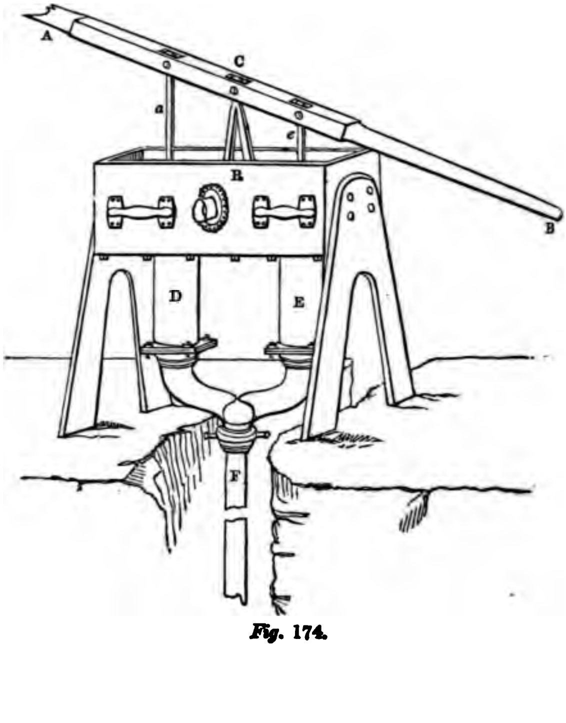


Fig. 174.

with the pipe F which descends into the water to be raised; *a* and *e* are the piston rods, attached to a double handle A B turning on the centre C; R is a trough which receives the water as it is thrown up by the pumps. By means of pipes proceeding from this trough, the water may be conveyed to any distance.

The Archimedean Screw.

192. This simple and beautiful contrivance for raising water was invented by the great Archimedes. It simply consists of a pipe wound, in a spiral form, about a solid cylinder A B, which is made to revolve on its axis by means of the winch H. The lower orifice *a* of the spiral tube dips into the water to be raised, and it is discharged at the upper orifice. As the cylinder is turned round, the water, which enters the orifice *a* at each revolution, runs down a series of inclined planes until it flows out at the upper orifice. In order to illustrate this action, let a marble be put into the pipe at *a*, then as the cylinder is turned round, the marble will continue to roll down a succession of inclined planes (formed at each revolution of the cylinder) until it is discharged at the upper orifice.

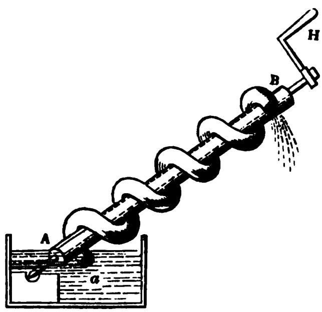


Fig. 175.

Hydraulic Ram.

193. This elegant and useful contrivance for raising water may be employed with advantage where there is an abundant supply of water with only a small descent.

This engine acts on the principle of accumulated work (see Art. 139.): a body of water acquires motion in its descent through an inclined pipe, A; and the outlet *k* upon being suddenly closed, allows the work accumulated in this body of water to expend itself in forcing some of the fluid, in the pipe B, into an air chamber *d*, whence it is raised by the pressure of the air in the chamber to any proposed elevation.

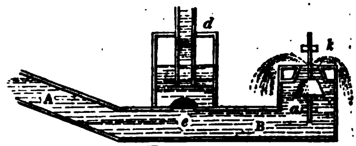


Fig. 176.

A is an inclined pipe conducting a stream of water from a reservoir; B a horizontal portion of this pipe, having a valve *e* opening into the air chamber *d; a* is a heavy valve which closes, when it is lifted upwards, the outlet of the water at *k;* this valve is so heavy that it descends in the quiescent fluid by its own weight, thereby opening the outlet at *k*, at the same time it is capable of being lifted up by the impetus of the water as it rushes out of the opening *k* with the velocity acquired in descending the inclined pipe A.

The valve *a* being first opened, the water, rushing out of the orifice *k*, at length acquires a velocity sufficient to drive the valve *a* upwards, thereby closing the orifice *k;* the current of water through *k* being thus suddenly checked, expends the work accumulated in it in forcing some of the fluid through the valve *e* into the chamber *d*. Now when the water has become quiescent, the heavy valve *a* descends by its own weight, and opens the orifice *k;* the water again rushes out of the orifice, and so on as already described.

Suction Ram.

194. The principle of this engine is similar to that of the preceding one.

Water flows from the reservoir A through the pipe ABDK;

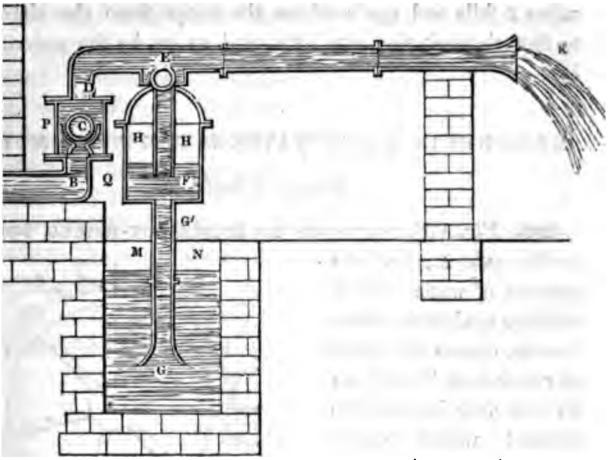


Fig. 177.

a heavy ball valve which, upon being lifted up, closes ›rifice D; MN is the well from which the water is to be d; GG′ is a pipe having a valve at G′, passing from the r in the well into the bottom of an air chamber HH, con-:ted exactly as in the forcing pump, Art. **185.**; E is a ɜ lifting upwards, which opens and closes, as the case be, the communication of the vertical pipe H with the EK. The motion of the water through the pipe ABDEK ıstained by the pressure of the water in the cistern A. :n the water has attained a sufficient velocity, the valve lifted up and the orifice D closed (see the description of hydraulic ram); the water in the horizontal pipe DEK, the velocity it has acquired, continues to discharge ? at K, thereby forming a vacuum or void in the inner .on of the pipe; the pressure of the atmosphere then s the water from the well MN into the pipe DEK; this r is discharged at K along with the water proceeding the cistern A. When the water becomes quiescent, the

valve C falls and again allows the water from the c
to flow through the pipe DEK, and so on, to the su
lift.

MACHINES IN WHICH WATER IS THE PRIME I

Water Wheels.

195. *Fig.* 178. represents an UNDERSHOT-WHEEL, on the axle A; MN is a current of water, which striking against the *float-boards*, causes the wheel to revolve on its axle A; on this axle is fixed the toothed wheel which drives the machinery.

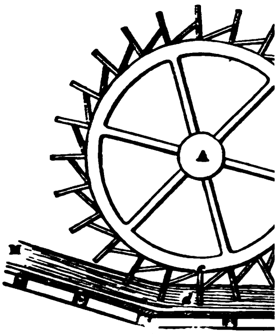


Fig. 178.

In Poncelet's under-shot wheel the float-boards are curved towards the direction of the current, so that the water rolls up their surface and does not leave the all its work is spent upon the wheel.

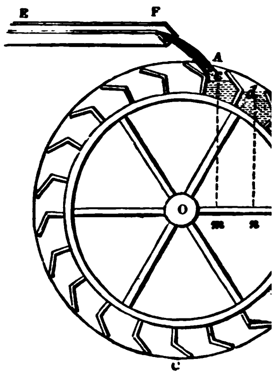


Fig. 179.

Fig. 179. represents an OVERSHOT-WHEEL, turning on its centre O; EF is a stream of water flowing over the top of the wheel, into the buckets *c*, *d*, &c., fixed upon the rim of the wheel; the gravity of the water in these buckets causes the right hand side ABC of the wheel to be heavier e other side, where the buckets are empty, being all upside down; hence the wheel revolves in the direc-ɔ. Let *c m* and *d n* be perpendiculars let fall from the of gravity of the water in the two buckets *c* and *d* vely, then o *m* will be the leverage of the water in ket *c*; and o *n* that of the bucket *d*; the bucket B, in izontal line O B, will have the greatest leverage, and ently will act with the greatest efficiency in moving el. As the buckets descend below B, they not only ı a decreasing leverage, but the water which they is continually flowing out of them, until they arrive en they become completely empty.

Barker's Mill.

This simple and elegant engine is moved by the of water undergoing . CD is a hollow cylin-ning on a vertical axis; a horizontal cylinder, icating internally with ıer; at the extremities horizontal cylinder two s A and B are made in ːs, opening in *opposite* ıs. On the continuation vertical axis, the upper ıe S is fixed, and there-olves with it; H is the elivering the corn to be A continuous stream flows through the pipe he cylinder C D. Let us

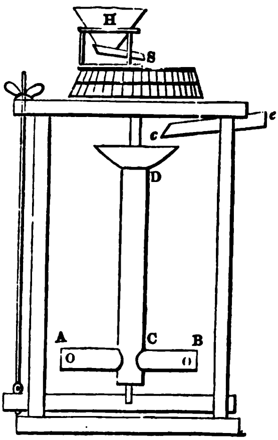


Fig. 180.

that the cylinder C D, with its horizontal branch A B, ɜd with water; then the pressure of this column of cause the water to be projected in jets from the orifices A and B in opposite directions; then the recoil or reaction of these jets upon the extremities of A and B, gives a rotatory motion to the whole machine upon the vertical axis.

Or, to take another view of the principle of action in this machine: if the orifices at A and B were closed, the column of fluid in the vertical tube CD would press equally on both sides of the horizontal tube AB; but when the orifices A and B are opened, the pressure on these parts is released, while the pressure upon the sides opposite to them remains the same; hence the tube AB revolves in the direction of the greater pressure; that is, in a direction contrary to that of the jets of water.

CHAP. X.

THE STEAM ENGINE.

Savery's Engine.

197. This engine was used for raising water from deep mines; the principle on which it acts may be explained as follows: — C is a large cylindrical vessel, called *the receiver,* into which steam enters by *the steam pipe* S, communicating with a strong boiler, called *the steam boiler,* where steam at a high pressure is generated; the steam pipe S has a cock *a,* called *the steam cock,* which opens and closes the communication of the receiver with the steam boiler; I is *the injection pipe,* which conveys a jet of cold water into the interior of the receiver, for the purpose of condensing the steam; this pipe has also a cock *b,* called *the injection*

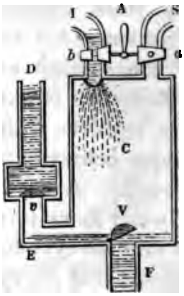


Fig. 181.

cock; these two cocks, *a* and *b*, are turned by the same handle A, so that when *b* is open *a* is closed, and *vice versâ;* F is a pipe descending into the water which is to be raised; at the top of this pipe is the valve V, lifting upwards; ED is a pipe proceeding from the bottom of the receiver to the cistern, into which the water is to be discharged; in this pipe is placed the valve *v*, lifting upwards.

To work the engine, the steam cock *a* is opened and *b* is shut; then the steam, rushing along the steam pipe S, enters the receiver C, and drives the air out of it, through the valve *v*. When the receiver is filled with steam, the steam cock *a* is closed, and at the same time the injection cock *b* is opened; then the jet of cold water, proceeding from the injection pipe, instantly condenses the steam in the receiver, and a vacuum is formed; the pressure of the atmosphere on the surface of the water in the well or pit forces the water up the pipe F, and nearly fills the receiver. The engine-man now lays hold of the handle A and opens the steam cock *a*, at the same time that he closes the injection cock *b*; the steam again enters the receiver, and by its great elastic pressure, exerted upon the surface of the water, forces the water, through the valve *v*, up the pipe ED, to the top of the pit or mine. In the same manner the engine is made to perform any number of strokes.

The defects of this engine are as follows: 1. It is limited in its application to the raising of water; 2. There is a great loss of power, at each successive lift, occasioned by the steam coming in contact with the cold water in the receiver.

Newcomen's Engine, with the Crank and Fly-wheel.

198. This engine was a great improvement upon Savery's. Its leading features are represented in *fig.* 182. C is the boiler communicating with the cylinder E by means of

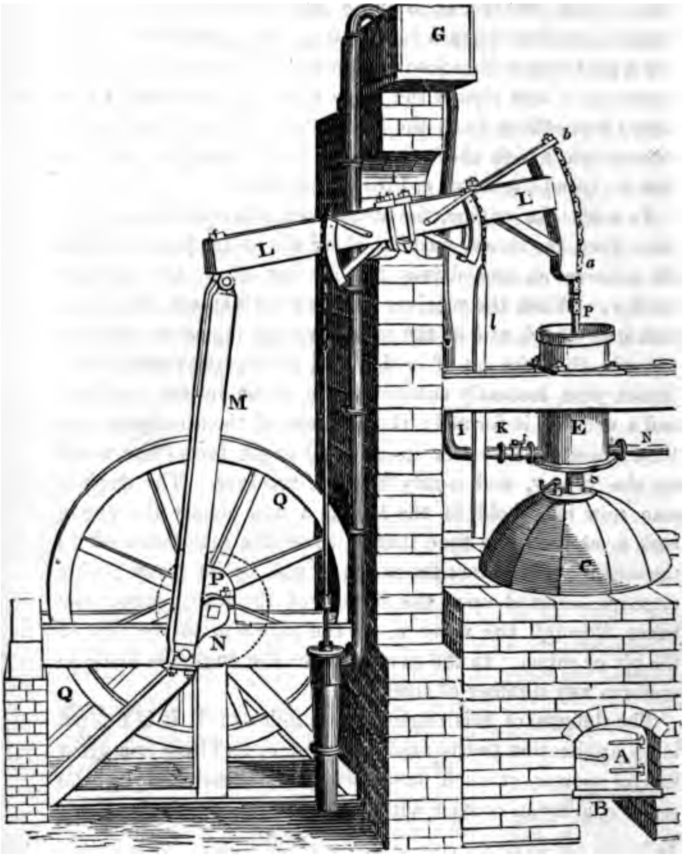


Fig. 182.

the steam pipe S; P is the piston rod connected with a solid piston which works steam-tight in this cylinder; the rod P of the piston is connected with the chain which coils round the arched head *a b* of the great beam L L; so that as the piston descends the extremity of the great beam is drawn

, and at the same time the
ı rod does not deviate from its
al position; G is a cistern of
water called the *injection cis-*
from this descends the injec-
pipe GIK (see also fig. 183.),
ı enters the bottom of the
ler; K is the *injection cock;*
opposite side of the cylinder
is a lateral pipe, turning up-
s at the extremity, having a

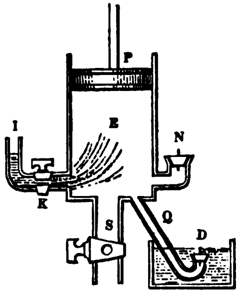


Fig. 183.

N, called the *snifting valve*, lifting upwards; Q is the *ion pipe* for drawing off the water formed in the cylin- the extremity D of this pipe is inserted in a vessel of , and has its orifice closed by a valve lifting outwards. ıen the engine is required to be put in action, let us se that the piston P is drawn to the top of the cylinder; eam cock S is opened, and the injection cock K is closed; the steam, having a pressure a little above that of the phere, flows from the boiler into the cylinder, and s out the air through the snifting valve N; when the ler is completely filled with steam, the steam cock S is l, and the injection cock K is opened, then a jet of cold is thrown into the cylinder, which instantly condenses team; a vacuum being thus formed, the pressure of the phere upon the top of the piston causes it to descend; the piston has arrived at the bottom of the cylinder, the cock S is again opened and the injection cock K closed; the steam again enters the cylinder, blows out as before ir that may have got in, and forces the water, formed cylinder by the condensation of the steam, down the ion pipe Q; this water escapes by the valve D into the n; the steam beneath the piston now balances the pres- of the external air, and a counterpoise at the opposite f the great beam raises the piston in the cylinder; but engine represented by *fig.* 182. this is effected by the momentum of the fly wheel QQ. In the same manner any number of strokes are performed. In this engine the pressure of the atmosphere is the moving power, the steam being merely employed to form the vacuum beneath the piston. With the crank and fly wheel this engine was employed as a prime mover of machinery generally, and the whole of its parts were made self-acting by Beighton and Smeaton. Its defects are as follows: 1. The want of uniformity in the action of the moving power; 2. The loss of power, at every upward stroke of the piston, from the condensation of steam by the cold cylinder; for it will be observed, that at every downward stroke the cylinder had to be cooled down by the injection water. These defects are completely remedied in Watt's double-acting engines, by introducing a separate vessel, called the condenser, where the steam is condensed, and by using the steam not merely to form a vacuum, but also to move the piston up and down by its elastic pressure.

Watt's Engine.

199. The first engine constructed by Watt was what is called the atmospheric engine, which only differed in principle from Newcomen's, by having the steam condensed in a vessel separate from the cylinder. He afterwards employed the steam to produce an upward as well as a downward stroke, and from this circumstance the engine has been called the double-acting condensing engine. This new principle required that the piston rod should be connected with the extremity of the great beam, in such a manner that the motion of the piston should be communicated to the beam in both directions of the stroke; this led to the invention of the parallel motion described in Art. **160.** of this work. Various other mechanical artifices were also introduced by him, to render the machine perfect in all its parts; such as the contrivances for lifting the valves so as to distribute the steam in the manner required for the proper action of the steam upon the piston, also the governor described in Art. **135.**, &c.

200. *Double-acting Condensing Engine, the Condenser, &c.*—*Fig.* 186. represents a section of the cylinder and con-

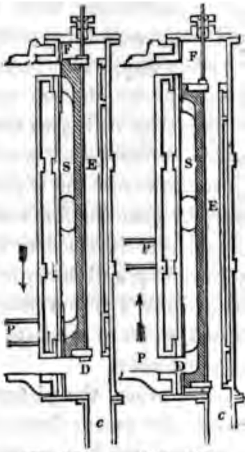


Fig. 184. *Fig.* 185.

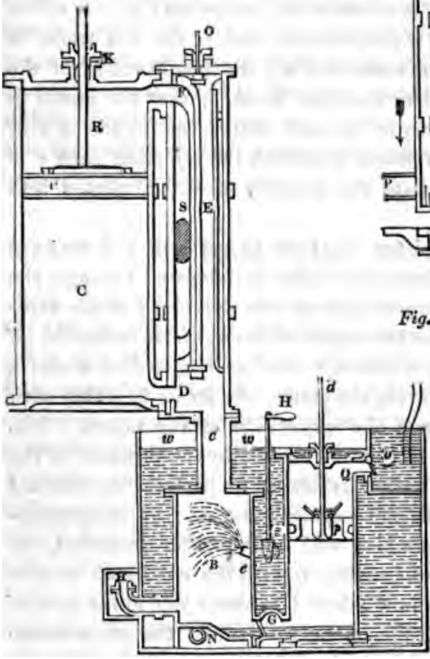


Fig. 186.

denser of a double-acting engine. C is the cylinder closed on all sides, excepting at the orifices F and D, for admitting the steam above and below the piston P; the piston rod R passes through a *stuffing-box* K, rendered steam-tight by being packed with lint and tallow; this piston rod is connected with the parallel motion described in Art. 160. B is the *condenser*, where the steam is condensed by a jet of cold water proceeding from the injection cock *e; w w* is the cold water well surrounding the condenser; *p* is the piston of the *air pump*, which pumps out the air and water collected in the condenser, thereby rendering the vacuum more complete; G is a valve, lifting to the right, which opens the communication between the condenser and air pump; Q is a valve, lifting towards the right, through which the hot water is pumped into the *hot water well o;* the piston rod *d* of the air pump is attached to the great beam, so that the piston *p* is moved up and down in the same manner as the piston P of the cylinder; H is a handle by which the injection cock *e* is turned, so as to regulate the quantity of water injected into the condenser.

Now, when the piston is about to perform a downward stroke, the steam from the boiler is admitted through the opening F into the upper part of the cylinder; at the same time the steam in the lower part of the cylinder is carried off through the opening D into the condenser B, so that whilst a vacuum is kept up below the piston, the steam is acting with its full pressure upon the upper side of the piston. The piston is, therefore, forced downwards by the pressure of the steam. When the piston is about to perform an upward stroke, the conditions are exactly reversed: by an arrangement of mechanism, which will be hereafter described, the communication of the opening D with the condenser is shut off, and the steam is now allowed to enter the lower part of the cylinder through the opening D, whilst the communication between F and the condenser is opened, and the steam in the upper part of the cylinder passes off into the condenser; in this case, therefore, the steam is acting with its full pressure upon the under side of the piston, whilst a vacuum is kept up above the piston. The piston is therefore forced upwards by the pressure of the steam. It must be observed that a perfect vacuum is never attained in the condenser, in consequence of the vapour arising from the water.

VALVES FOR REGULATING THE DISTRIBUTION OF THE STEAM THROUGH THE CYLINDER.

201. There are various contrivances now in use for regulating the distribution of the steam. In the engines constructed by Watt, the valves were opened and closed by means of pins, or tappets, fixed to an oscillating rod, called the plug-tree, attached to the great beam of the engine. In engines of moderate power, much more simple contrivances have been adopted, such as the slide valve, the D-valve, and the four-way cock.

SLIDE VALVES, ETC.

202. *Locomotive Engine, with the common Slide Valve.—Fig.* 187. represents the common slide valve, with its relation to the other parts of the engine, as commonly used in our locomotives. Here P is the piston, moving in the cylinder C, which in a locomotive engine lies in a horizontal position; CD is the piston rod passing through the stuffing box K; DE is the connecting rod, being connected with the piston rod by a joint at D; EF is the crank attached to the axle F of the driving wheel of the carriage; the effect of this mechanical arrangement is, that whilst the piston moves backwards and forwards in the cylinder, the connecting rod and crank transmit this motion, so as to give a rotatory motion to the axle of the driving wheels, which moves the carriage forward on the rail. We have now to consider a distinct piece of mechanism, for moving the slide valve up and down in the *steam box* AB, so as to regulate the distribution of the steam in its passage into the cylinder. The motion of the slide valve must be so adjusted that when the piston is ascending the steam must be entering the under part of the cylinder, while the steam above the piston is allowed to escape into the atmosphere, as in the case of a high pressure engine, or allowed to pass into the condenser in a condensing engine; on the contrary, when the piston is descending, the steam must be entering the upper part of the cylinder, while the steam below the piston is allowed to escape into the atmosphere, or the condenser,

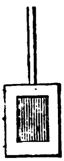


Fig. 190.

Fig. 189.

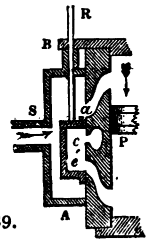


Fig. 188.

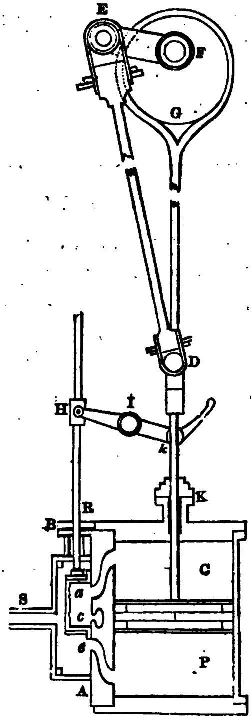


Fig. 187.

as the case may be. In *fig.* 187. A B is *the steam box*, which is kept constantly filled with steam by the steam pipe S, proceeding from the boiler; *the slide valve* is moved up and down by the rod R H passing through a stuffing box R; *a* is the upper steam port or orifice leading into the top of the cylinder, and *e* is the lower steam port; exactly between these ports is an opening *c*, which conducts the steam into the condenser, or the atmosphere, as the case may be; G is an eccentric wheel, which turns upon the axle F as a centre *of motion*; G*k* is the eccentric rod attached to the extremity of the lever *k*H, turning on the fixed centre I; the extremity H of this lever is attached to the rod of the slide valve, so that when the piston P is ascending the slide valve is descending, and *vice versâ* (see Art. **200.**). *The slide valve* is a piece of metal hollowed on one face, and made to connect two of the openings, *a*, *c*, *e*, on the side of the cylinder, at one time. *Fig.* 189. shows a separate longitudinal section of the valve, and *fig.* 190. shows a view of its hollowed face. This face lies flat against the side of the cylinder, so that the steam, in the steam box, cannot pass beneath the face of the valve.

In *fig.* 187. the piston P is supposed to be ascending, and the steam is passing through the lower port *e* into the under part of the cylinder, at the same time the steam is passing from the upper part of the cylinder through the upper port *a*, and is discharged through the centre port *c*. When the piston has performed an upward stroke, and begins to descend, as in *fig.* 188., the valve has made a downward stroke, and now connects the lower steam port *e* with the centre port *c*, leaving the upper port *a* open for the steam to enter the upper part of the cylinder; and so on to any number of strokes.

In practice it is customary to have the motion of the valve so adjusted, that the steam port may be slightly open when the piston has completed its stroke. The small space thus open is called the lead of the valve. This lead allows time for the steam to enter the cylinder, so as to prepare for the succeeding stroke of the piston.

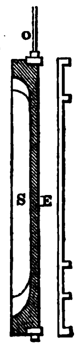


Fig. 191.

203. *The* D-*valve.* — *Figs.* 184, 185, and 186, represent sections of this valve at different positions of the piston.

Fig. 191. represents a longitudinal section of the valve itself; O is the valve rod working through the stuffing box; E is an opening passing through the valve, of which a transverse or cross section is shown in *fig.* 192.; S is the hollow in the valve through which the steam passes to the top or bottom of the cylinder, as the case may be; *a b*, in *fig.* 192., is the packing at the back of the valve, which works steam-tight against the valve box. This is called the D-valve, from the form of the cross section, shown in *fig.* 192.

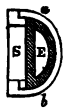


Fig. 192.

In *fig.* 186., S is the mouth of the steam pipe proceeding from the boiler; *c* is the pipe leading to the condenser B; O is the rod by which the slide valve is moved up and down; E the longitudinal opening passing through the valve; F the port leading into the upper part of the cylinder, and D the lower port leading into the lower part. Now in the position of the slide valve shown in *fig.* 186., the steam enters at S. then passing through the hollow of the valve, enters the upper port of the cylinder through the opening F, and causes the piston to descend; at the same time the steam, from the lower part of the cylinder, passes through the port D into the condenser B. On the contrary, in the position of the valve shown in *fig.* 185., the steam, passing through the hollow of the valve, enters the lower part of the cylinder through the port D, while at the same time the steam in the upper part of the cylinder escapes through the port F, and, descending through the longitudinal opening E in the valve, enters the eduction pipe *c* leading to the condenser. *Fig.* 184. represents an intermediate position of the valve. The valve is moved by an eccentric, precisely in the same manner as described in Art. **202.**

THE FOUR-WAY COCK, WITH ITS APPLICATION.

204. This simple and beautiful mode of distributing the steam is represented in *figs.* 193. and 194. S, B, C, T are four tubes; S communicates with the boiler; C leads to the condenser, or to the external air, according as the engine is a condensing or a high pressure one; B leads to the bottom of the cylinder, and T leads to the top of the cylinder. These four tubes enter a cock which has two curved passages leading through

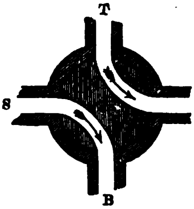


Fig. 193.

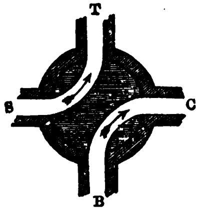


Fig. 194.

it, as shown in the figures. These passages are cut in such a manner, that by turning the cock, they may be made to open a communication between any two adjacent tubes. In the position of the cock, shown in *fig.* 193., the steam is passing through the tube B, to the bottom of the cylinder; at the same time the steam is passing from the top of the cylinder, through the tube T, into the tube C leading to the condenser. In *fig.* 194. the cock has performed a quarter of a revolution: the steam is now passing through the tube T, to the top of the cylinder; at the same time the steam is passing from the bottom of the cylinder, through the tube B, into the tube C leading to the condenser. The eccentric is usually employed to move the cock, after the manner described in Art. 202.

205. *Leupold's High Pressure Engine.* — The four-way cock was invented by Leupold. He employed it in a high pressure engine, of which *fig.* 195. is a representation; where A is the boiler; E and C are two cylinders in which the pistons *e* and *c* work; F the waste steam pipe proceeding from the four-way cock. The piston rods D and G are attached to the extremities of two great beams, quite distinct from each other, but at the same time so adjusted, that whilst D is ascending G should be descending, and so on. The effect of this contrivance is the same as that of a double-acting engine. The pressure of the steam em-

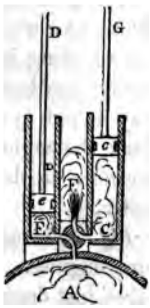


Fig. 195.

ployed must be considerably above that of the atmosphere, since the upward stroke of each piston is performed by the pressure of the steam beneath it, whilst the upper side of the piston undergoes the pressure of the atmosphere. In the position of the four-way cock, shown in the figure, the steam is passing into the lower part of the cylinder E, and at the same time the steam is making its escape from the lower part of the cylinder C, through the waste pipe F, into the atmosphere. It will be observed that the motive force of the steam is only employed during the ascent of each piston.

APPENDAGES OF THE STEAM BOILER.

The following appendages of the boiler have not been described in the foregoing portion of this work. See Arts. **136.** and **137.**

THE SAFETY VALVE.

206. The safety valve is used to secure the boiler from bursting by the excessive pressure of the steam. *Fig.* 196. represents *the lever safety valve*, where AB is the lever with its load L, pressing upon the head of the valve *v* which closes the opening S leading into the boiler. By sliding the load L along the lever, any amount of pressure may be put upon the valve that may be found necessary to work the engine. The divisions upon the lever enable the engineer to determine the elasticity of the steam in the boiler.

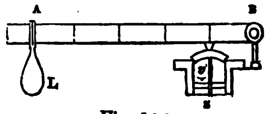


Fig. 196.

Fig. 197. represents *the spring safety valve* for high pressure engines. This only differs from the common safety valve just described, in having the extremity A, of the lever AB, pressed down by means of a spring in the place of a load, which would be inconveniently large in the case of high pressure engines. Here AB is the lever turning on the fixed centre B; *v* the conical valve, opening or closing, as the case may be, the pipe S proceeding from the boiler; C the point in the lever to which the pin of the valve is attached; D is a case containing the spring which draws the extremity A of the lever downwards; *n* is a nut, which screws upon the rod R, for adjusting the force of the spring exerted upon the extremity of the lever; N is a pointer with a graduated scale, for indicating the amount of pressure produced upon each square inch of the valve. Now as the nut *n* is turned, the spring becomes more and more compressed, and the pointer N indicates the number of pounds per square inch with which the valve *v* is pressed downwards. Thus, if the pointer stands at 40lbs., then the steam will be retained in the boiler so long as its pressure does not exceed 40 lbs. per square inch; but when the pressure of the steam exceeds this quantity, the valve *v* is raised and a portion of the steam is allowed to escape, which tends to lessen the elasticity of the steam in the boiler, and hence the steam is always kept at or near the pressure indicated by the pointer.

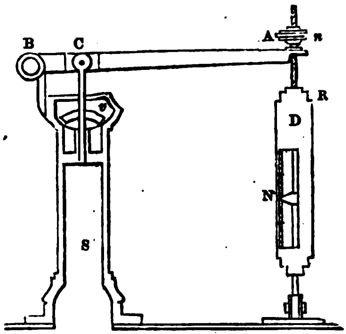
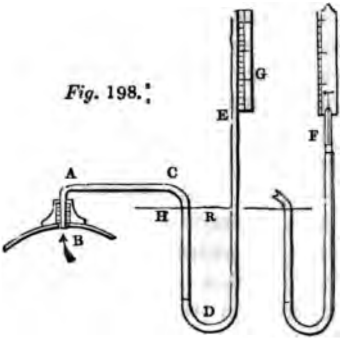


Fig. 197.

THE STEAM GAUGE.

207. This instrument is designed to indicate the degree of pressure of the steam which is used in working the engine. *Fig.* 198. represents a mercurial steam gauge; ACDE is a bent tube, open at both extremities, passing from the vessel B containing the steam; G is a graduated scale for indicating the height of the mercury in the leg DE. When the pressure of the steam is equal to that of the external air, the mercury in the two legs, CD and DE, stands at the same level HR; but when the pressure of the steam is greater than the external air, the mercury is depressed in the leg CD and elevated in the leg DE. The excess of pressure of the steam above that of the atmosphere is found by observing the difference of the levels of the mercury in the legs DE and DC, and then allowing half a pound, as the pressure of the steam on each square inch, for every inch in the difference of the levels. The bent tube is frequently made of iron: in this case a float F with a rod and pointer, is inserted into the open end of the tube; as the float F is raised or depressed with the mercury, the pointer is made to indicate the difference of the levels of the mercury in the two legs of the instrument.

Fig. 198.



THE WATER GAUGE.

208. This simply consists of a bent glass tube ADCB; where one extremity, A, enters the boiler above the proper level HR of the water, and the other extremity, B, enters below the proper level; as the water must stand at the same level in the glass tube DC that it does in the boiler, the eye of the engineer will at once see what depth of water is in the boiler. Another kind of water gauge is explained in the general description of the steam engine. (Art. **210.**)

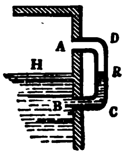


Fig. 199.

FORMS OF BOILERS.

209. In the construction of steam boilers two things are specially to be observed :—1st. The boiler should have that form which, under the given circumstances, is best calculated to resist the expansive force of the steam as well as the destructive action of the heat. 2nd. The fire of the furnace should act upon a large extent of that portion of the plate which is in contact with the water. *Fig.* 200. represents a longitudinal as well as a cross section of what is called the Butterly boiler, which is much used in our manu-

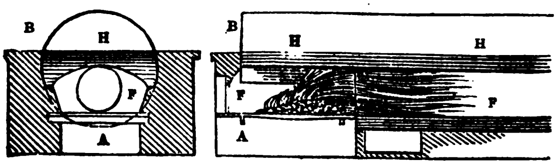


Fig. 200.

facturing districts. A represents the ash-pit, F F the furnace, B the boiler, and H H the level of the water in the boiler. The concave form given to the bottom of the boiler obviously brings a larger extent of surface in contact with the flame, than would take place if the bottom were flat.

For the various practical details connected with the construction of boilers, &c., the student may consult Bourne's "Treatise on the Steam Engine."

GENERAL VIEW OF A DOUBLE-ACTING CONDENSING ENGINE.

210. *The steam boiler* and its appendages are represented in *fig.* 201. Here F is the furnace; BB the water in the boiler; WW the space occupied by the steam; Q is the steam pipe which conducts the steam to the cylinder; *cabw* the safety valve (see Art. **206.**); OV the pipe of the water regulator, s being the float, &c. (see Art. **136.**); *i* a pipe, proceeding from the hot water well, which supplies the boiler with water; *c* and *c′* are the water gauges; the former, *c*, is called *the water-cock*, because it communicates with the water in the boiler, whereas *c′* is called the *steam-cock* because it communicates with the steam in the boiler; when the water in the boiler stands at a proper level, upon opening the two cocks, water will issue from the water-cock *c*, and steam from the steam-cock *c′*; but if the boiler contains too little water, the steam will issue from both cocks; *t t* is another form of the water gauge (see Art. **208.**)

211. *The engine*, with its various parts, is represented in *fig.* 202. Here BF is the great beam turning on the centre A; BK the parallel motion (see Art. **160.**); EP the piston rod, attached to the piston P; C the cylinder; S the steam pipe transmitting steam, through the four-way-cock, to the top and bottom of the cylinder, as explained in Art. **204.**; J is the condenser, and O the air pump, surrounded by the cold water in the cold water well LL (see Art. **200.**); W is the hot water well, from which water is pumped through the pipe *ii* to the reservoir V, which supplies the boiler with hot water as it is required; N, the rod working this pump, is attached to the great beam; M is another rod, attached to the great beam, working the pump S, which supplies the cold water well with a constant stream of cold water; FR is the connecting rod and crank, giving a rotatory motion to the *fly* wheel HH, (see Art. **27.**); the eccentric, fixed to the

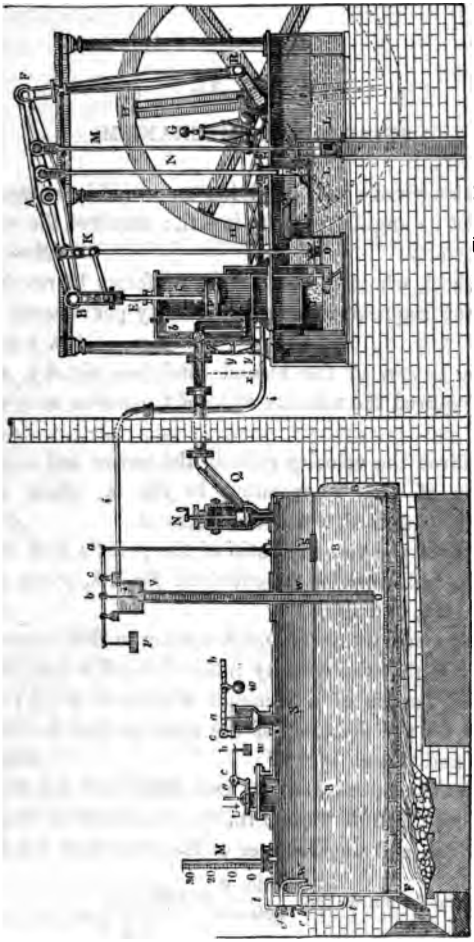


Fig. 202.

Fig. 201.

axle of the crank, as shown in the figure, works the four-way-cock, as explained in Art. **152.**; G is the governor, regulating the supply of steam to the cylinder, as explained in Art. **135.**

CHAP. XI.

PROBLEMS ON MECHANISM.

1. The length of a rod, revolving on one of its extremities, is 6 ft., and its angular velocity is 4 ft.; required the velocity of its extremity. *Ans.* 24 ft.

2. A wheel, whose radius is 4 ft., performs 12 revolutions per minute; required its angular velocity per second. *Ans.* 1·2566 ft.

3. In a LEVER of the second kind (see *fig.* 4.), AF=7, BF=3; required the velocity ratio of the power and weight. *Ans.* $2\frac{1}{3}$.

4. Required the velocity ratio of the power and weight in the system of rods represented in *fig.* 6., when AC=5, CB=2, BQ=6, QD=3, DR=7, and RE=1. *Ans.* 35.

5. Required the velocity ratio of the point A and the rod GK, in the link-work represented in *fig.* 10., when AB=9, BC=2, DE=6, and EF=3. *Ans.* 9.

6. Draw a SYSTEM OF PULLEYS, similar to that represented in *fig.* 26., so that the velocity ratio of P and W may be 16.

7. If the handle of a common WINDLASS is $2\frac{1}{2}$ ft. long, what must be the diameter of the axle, so that the velocity ratio of P and W may be 10? *Ans.* 6 in.

8. In the COMPOUND WHEEL AND AXLE (see *fig.* 42.), the length of the handle PO=2 ft., the diameter of the large axle A=10 in. and the diameter of the small axle D=$9\frac{1}{2}$ in.; it is required to show that $\frac{\text{velo. P}}{\text{velo. W}}=192$.

9. What must be the difference between the diameters of the axles, in a compound wheel and axle, so that the velocity ratio of P and W may be 100, when the length of the handle is $2\frac{1}{2}$ ft.? *Ans.* $\frac{1}{10}$ ft.

10. It is required to find the velocity ratio of P and W in the wheels and axles represented in *fig.* 43., when the diameter of F=20 in., diameter CB=6 in., diameter AD =50 in., and the diameter E=3 in. *Ans.* $\frac{500}{9}$.

If P descend 4 ft., through what space will W ascend? *Ans.* ·072 ft.

11. If the diameters of the wheels, in the last problem, are 3 times the diameters of their respective axles, then $\frac{\text{velo. P}}{\text{velo. W}}$ =9.

12. In *fig.* 20., if the diameter of the wheel DC is 18 in., what must be the diameter of the wheel AB, so that it may make 4 revolutions whilst DC makes 3?

In this case 4 revolutions of AB must be equivalent to 3 revolutions of DC; and therefore 4 times the diameter of AB must be equal to 3 times the diameter of DC. Hence we have

$$4 \times \text{diam. AB} = 3 \times 18,$$

$$\therefore \text{diam. AB} = \frac{3 \times 18}{4} = 13\tfrac{1}{2} \text{ in.}$$

13. To determine the synchronal rotations (or rotations performed in the same time) of the axes of SPEED PULLEYS.

(1.) In *fig.* 20. let the diameter of the pulley DC=9 in., the diameter of AB=6 in.; required the least number of complete rotations which the axes of the pulleys must respectively make in the same time.

Let DC make 1 revolution, then (Art. **34.**)

$$\text{No. revo. AB} = \frac{9}{6} = \frac{3}{2},$$

thus it appears, that whilst DC makes 1 revo., AB makes $1\frac{1}{2}$; therefore, doubling the no. of revolutions of each, whilst DC makes 2 revo. AB makes 3.

(2.) Required the same as in the preceding example, when D and d are put for the diameters of the pulleys DC and AB respectively, and Q and q the number of revolutions which the axes KQ and BP respectively make in the same time.

Here the spaces described by the circumferences of the wheels in the same time are equal, but the one wheel makes Q revo. whilst the other makes q,

$$\therefore \text{ space described by circum. } CD = \pi D \times Q,$$
$$\text{and} \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad AB = \pi d \times q,$$
$$\therefore \pi D \times Q = \pi d \times q,$$
$$\therefore D \times Q = d \times q \ldots (1),$$
$$\therefore \frac{Q}{q} = \frac{d}{D} \ldots (2).$$

In the foregoing example, $D = 9$, and $d = 6$;

$$\therefore \frac{Q}{q} = \frac{6}{9} = \frac{2}{3};$$

that is, the synchronal rotations are, $q = 3$, and $Q = 2$.

(3.) In a group of speed pulleys (see *fig.* 44.), let the sum of the diameters of the driver and follower = 30 in., and let the driver perform 1 revo. whilst the follower performs 9; required the diameters of the pulleys.

Here the diameter of the driver must be 9 times that of the follower; therefore the diam. of the follower = 3 in., and the diam. of the driver = 27.

Or generally, let d = the diameter of the driver, S = the constant sum of the diameters of the driver and follower, and q, Q = the no. of rotations which they respectively perform in the same time; then

$$\text{diameter follower, or } D = S - d;$$

substituting this in eq. (2), we have

$$\frac{Q}{q} = \frac{d}{S - d} \ldots (3);$$

$$\therefore d = \frac{QS}{Q + q} \ldots (4).$$

In the preceding example, $q = 1$, $Q = 9$, and $S = 30$; $\therefore d = \frac{9 \times 30}{9 + 1} = 27$.

(4.) To find the diameters of a set of five speed pulleys, *which shall* produce a series of velocity ratios in the axes, corıding to the geometrical series $\frac{1}{9}$, $\frac{1}{3}$, 1, 3, 9 ; the con- sum of the diameters being 30.

ɪre the diameter of the first driver must be $\frac{1}{9}$ of that of ɔllower ; therefore, the diam. 1st driver = 3 in., and its wer = 27 in.

he diam. of the 2nd driver must be $\frac{1}{3}$ of that of its follower ; 'efore the diam. 2nd driver = $7\frac{1}{2}$ in., and its follower $2\frac{1}{2}$ in.

Γhe diameters of the 3rd pair will be equal, and therefore ;h equal to 15 in.

The diameters of the 4th pair will be the reverse of those the 2nd pair; and those of the 5th pair the reverse of ıe 1st.

Hence the diameters of the pulleys on each axis will be as ɔllows: 3 in., $7\frac{1}{2}$ in., 15 in., $22\frac{1}{2}$ in., and 27 in.

In this example the velocity ratio may be written as follows: $\frac{1}{3^2}$, $\frac{1}{3}$, 1, 3, 3^2; where the last term is *the reciprocal* of the first, and the last but one the reciprocal of the 2nd, and so on. Again, the number of terms is 5, and the common ratio is 3; now the exponent, 2, of the first and last terms is found thus:

$$2=\frac{5-1}{2}, \text{ that is,}$$

$$\text{the exponent}=\frac{\text{no. terms}-1}{2};$$

this will be hereafter shown to be generally true. As anothe example, we have the ratios $\frac{1}{27}$, $\frac{1}{3}$, 3, 27, or $\frac{1}{9^{\frac{3}{2}}}$, $\frac{1}{9^{\frac{1}{2}}}$, $9^{\frac{1}{2}}$, $9^{\frac{3}{2}}$; wher the common ratio is 9, the number of terms 4, and the e ponent of the first and last terms $=\frac{3}{2}=\frac{4-1}{2}$, as in the ot case.

Generally, let n = the no. terms, r = the common ratio, m = the e nent of the first and last terms, and s = the constant sum of the di ters of any driver and its follower; then we have for the series of ratios

$$\frac{1}{r^m}, \frac{1}{r^{m-1}}, \ldots\ldots r^{m-1}, r^m;$$

where the value of m remains to be determined.

Now in order to produce the last term, r^m, the first term $\frac{1}{r^m}$ has been multiplied by r^{n-1};

$$\therefore \frac{1}{r^m} \times r^{n-1} = r^m,$$

$$\therefore r^{2m-n+1} = 1,$$

$$\therefore 2m - n + 1 = 0,$$

$$\therefore m = \frac{n-1}{2} \ldots (5).$$

We proceed now to find the diameters of the speed pulleys on the driving axis, in order to produce these velocity ratios. Let d_1, d_2, ... d_n = the diameters of the 1st, 2nd, ... and nth pulleys respectively, on the driving axis; then these symbols, taken in a reverse order, will be the corresponding diameters of the pulleys on the driven axis.

The ratio of the rotations of the first driver and its follower is $\frac{1}{r^m}$, therefore, by eq. (3),

$$\frac{1}{r^m} \text{ or } \frac{Q}{q} = \frac{d_1}{s - d_1},$$

$$\therefore d_1 = \frac{s}{1 + r^m} \ldots (6).$$

Again, the ratio of the rotations of the second driver and its follower is $\frac{1}{r^{m-1}}$, therefore, by eq. (3),

$$\frac{1}{r^{m-1}} = \frac{d_2}{s - d_2},$$

$$\therefore d_2 = \frac{s}{1 + r^{m-1}} \ldots (7);$$

and so on to any pulley in the series. It will be observed that the value of m is given in eq. (5).

In the preceding example, $n = 5$, $r = 3$, and $s = 30$; then, by eq. (5),

$$m = \frac{n-1}{2} = \frac{5-1}{2} = 2;$$

and by eq. (6), &c.,

$$d_1 = \frac{30}{1+3^2} = 3,\ d_2 = \frac{30}{1+3} = 7\tfrac{1}{2},\ d_3 = \frac{30}{1+3^0} = 15,$$

and so on; but the remaining diameters will be better found as follows: $d_4 = s - d_2 = 30 - 7\frac{1}{2} = 22\frac{1}{2}$, and $d_5 = s - d_1 = 30 - 3 = 27$.

As another example, let $n=4$, $r=1{\cdot}5$, $s=25$, then $m = \frac{4-1}{2} = \frac{3}{2}$, d_1

$$= \frac{25}{1+1{\cdot}5^{\frac{3}{2}}} = \frac{25}{1+1{\cdot}837} = 8{\cdot}8\ \ d_2 = \frac{25}{1+1{\cdot}5^{\frac{1}{2}}} = 11{\cdot}24,\ d_3 = 25 - 11{\cdot}24 = 13{\cdot}76,$$

$d_4 = 25 - 8{\cdot}8 = 16{\cdot}2$.

14. Where must the strap, going over the CONICAL AXLES (represented in *fig.* 45.) be placed so that the axes may revolve with the same speed?

15. If the diameters of the wheels in the speed pulleys, shown in *fig.* 44., be as the numbers 2, 4, 6, 8, and 10, show that as the strap is shifted from one pair of wheels to another, the relative velocities of the axes CD and AB are as the numbers 5, 2, 1, ½, and ⅕.

16. In *fig.* 47., what will be the position of the ECCENTRIC WHEEL C, when the axis D attains its greatest velocity?

17. If the spur wheel A (see *fig.* 51.) contain 60 teeth, how many teeth must the pinion B have, in order to revolve 15 times while A revolves 4 times? *Ans.* 16.

Show, by an example, that the IDLE WHEEL *b*, represented in *fig.* 55., does not affect the velocity ratio of the two wheels *a* and *c*.

18. Required the velocity ratio of P and W in the system of wheels shown in *fig.* 52., when diameter axle G=3 in., no. teeth in V=30, no. teeth in the pinion T=5, no. teeth in S=28, no. teeth in pinion R=8, and diameter wheel A =27 in. *Ans.* 189.

If W ascend 3 ft., through what space will P descend? *Ans.* 567.

19. In the TRAIN OF WHEELS represented in *fig.* 53., let the no. teeth in $N_1=40$, no. in $n_1=6$, no. in $N_2=30$, no. in

$n_2=7$, no. in $N_3=21$, no. in $n_3=8$; if N_1 makes 1 revolution, how many revolutions will n_3 make? *Ans.* 75.

20. To determine the synchronal rotations (or rotations performed in the same time) of the axes of TRAINS OF WHEEL-WORK.

(1.) Let the no. teeth in the driver $B=27$ (see *fig.* 51.), and the no. teeth in the follower $A=72$; required the least number of complete rotations performed by the axes in the same time.

No. revo. B × no. teeth in B = no. revo. A × no. teeth in A,

$$\therefore \frac{\text{no. revo. A}}{\text{no. revo. B}} = \frac{\text{no. teeth in B}}{\text{no. teeth in A}} \ldots (1),$$

$$= \frac{27}{72} = \frac{3}{8},$$

that is, whilst B makes 8 revolutions, A will make 3; and these are the least synchronal rotations, because the fraction $\frac{8}{3}$ is in its least terms.

In a train of wheels (see *fig.* 53.), let N_1 = the no. teeth in the first driver, n_1 = the no. teeth in the first follower, and so on as in Art. 62.; and moreover, let Q_1 = the no. of rotations of the first axis, Q_2 = the no. of rotations of the second axis, and so on; then by eq. (1)

$$\frac{Q_2}{Q_1} = \frac{N_1}{n_1} \ldots (2);$$

$$\text{similarly, } \frac{Q_3}{Q_2} = \frac{N_2}{n_2}, \frac{Q_4}{Q_3} = \frac{N_3}{n_3}, \ldots \frac{Q_{m+1}}{Q_m} = \frac{N_m}{n_m};$$

therefore, by multiplication and substitution, we have

$$\frac{Q_{m+1}}{Q_1} = \frac{Q_2}{Q_1} \times \frac{Q_3}{Q_2} \times \frac{Q_4}{Q_3} \times \ldots\ldots \times \frac{Q_{m+1}}{Q_m} \ldots (3)$$

$$= \frac{N_1}{n_1} \times \frac{N_2}{n_2} \times \frac{N_3}{n_3} \times \ldots \times \frac{N_m}{n_m} \ldots (4).$$

It will be observed that eq. (3) is simply derived from the circumstance that all the numerators but the last, in the right hand member, destroy all the denominators but the first. Eq. (4) is the same as that which is established in Art. 62., by another method of proof.

Eq. (3) may be expressed in language as follows:—*the ratio of the synchronal rotations of the first and last axes, is equal to the product of the separate synchronal ratios of the successive pairs of axes.*

It is evident, from eq. (4), that the drivers and followers may be placed in any order in a train of wheel-work.

(2.) Required to find a train of wheels which shall connect the hour-wheel of a clock with a wheel which revolves in a lunation, or in 29 days, 12 h. 45 min. nearly.

Reducing the periods to min., the hour axis of the clock must make 42525 revolutions whilst the axis of lunation makes 720. Therefore, eq. (4.), the product of the teeth in all the drivers must produce 720, and that of all the followers 42525;

$$\therefore \frac{42525}{720}=\frac{945}{16}=\frac{27\times 35}{4\times 4};$$

thus it appears that two pinions containing 4 teeth each, and two followers containing 27 and 35 teeth respectively, would produce the lunation. This mechanism is sometimes connected with clocks to show the moon's age.

(3.) In *fig.* 51., let the no. teeth in A=144, and the no. teeth in B=54; how many revolutions must the wheels make in order that the same teeth may come again in contact with each other.

Here, by eq. (1.), we have

$$\frac{\text{no. revo. A}}{\text{no. revo. B}}=\frac{54}{144}=\frac{3}{8};$$

that is, A must make 3 complete revolutions, or B must make 8, before the same teeth can again come in contact; for 3 and 8 are the least number of revolutions which the wheels can make, in order that the space described by the circumference of the one wheel may be equal to the space described by the circumference of the other.

Millwrights consider that the same individual teeth on the one wheel should come as seldom as possible into contact with the same teeth on the other wheel. On the contrary watchmakers imagine that the same pair of teeth should come into contact as frequently as possible.

Let an axis be required to revolve about 3 times as fast as its driving axis. In this case 36 teeth in the driver, and 12 teeth in the follower, would produce this relative rotation; and such an arrangement would suit the watchmaker, because the same teeth would come again into contact at every revolution of the large wheel; but the millwright would add one tooth (called the HUNTING COG) to the large wheel, that is to say, he would have 37 teeth in the large wheel and 12 in the other, because 37 and 12, being prime to each other, and nearly in the required ratio, the same pair of teeth would not come again into contact until the large wheel had made 12 revolutions, or the small one 37.

(4.) To determine the different combinations of teeth in the wheels of a clock, (see *fig.* 164.), when the number of teeth in each pinion is 8, and the number in each wheel is not to exceed 100 nor to be less than 40.

Let N_1 = the no. teeth in C, n_1 = the no. in G, N_2 = the no. in E, and n_2 = the no. in F; then as the axis FJ must revolve 60 times as fast as the axis BD, we have, by Art. 62.,

$$\frac{N_1 \cdot N_2}{n_1 \cdot n_2} = 60;$$

$$\text{but } n_1 = n_2 = 8,$$

$$\therefore N_1 \cdot N_2 = 64 \times 60;$$

here $N = 64$, and $N_2 = 60$, would form a good train; but in order to ascertain all the combinations, we shall throw the product, 64×60, into prime factors, thus $64 \times 60 = 2^8 \times 3 \times 5$, and then by distributing these factors into two groups, we find

First combination, $\overline{2^4 \times 3} \times \overline{2^4 \times 5} = 48 \times 80$,

Second „ $\overline{2^3 \times 5} \times \overline{2^5 \times 3} = 40 \times 96$,

Third „ $\overline{2^6} \times \overline{2^2 \times 3 \times 5} = 64 \times 60$, The last combination is probably the best, as the numbers are nearest to equality.

21. What must be the lowest number of teeth in the two last wheels of problem 19., so that n_3 may make 60 revolutions, while N_1 makes one? *Ans.* $N_3=21$, $n_3=10$.

22. A driving wheel is to have 10 teeth, and the follower 40; it is required to find the diameters of THE PITCH CIRCLES when the pitch of the teeth is 1 in. (See Art. 65.)

Ans. 3·183 in., and 12·732 in.

23. The diameter of the pitch circle is 16 in., and the pitch of the teeth 1¼ in., required the number of teeth in the wheel. *Ans.* 40.

24. The diameter of a pitch circle is 20 in., and the number of teeth 80; required the pitch of the teeth.

Ans. ·785 in.

25. If THE CROWN WHEEL B (see *fig.* 57.) contains 66 teeth, how many teeth must the pinion A contain, so that while it makes 22 revolutions the crown wheel may make 3?

Ans. 9.

26. If the diameter of the wheel P is 10 in. (see *fig.* 64.), what will be the length of the stroke of THE RACK AB in two revolutions of the wheel? *Ans.* 5·236 ft.

27. Required the velocity ratio of P and W, in THE RACK AND PINION shown in *fig.* 65., when the length of the handle $R=20$ in., the distance between the teeth in the pinion $r=\frac{3}{4}$ in., and the number of teeth in the pinion $=4$.

Ans. 41·9 nearly.

28. Required the same as in the last problem, for the combination shown in *fig.* 66., when the length of the handle $=18$ in., no. teeth in $r=7$, no. teeth in $R'=28$, no. teeth in $r'=6$, and the distance between the teeth of the rack $=$ 1 in. *Ans.* 75·4 nearly.

29. In the last problem, if $l=$the length of the handle, $n=$no. teeth in r, $n_1=$no. teeth in R', $n_2=$no. teeth in r', $a=$distance

between the teeth of the rack, and $\pi = 3{\cdot}1416$, show that $\frac{\text{velo. P}}{\text{velo. W}} = \frac{2\pi l n_1}{a n n_2}$.

30. In *fig.* 77., if the circumference of THE FRICTION WHEEL *a* or *b* is 9 in., and that of its axis *e* is $1\frac{1}{2}$ in., how many times is the extent of rubbing surface of the axis C greater than that of the axis *e*? *Ans.* 6 times.

31. In THE TRAIN OF WHEELS shown in *fig.* 78., give an arrangement of teeth which will cause M to make 60 revolutions in the same time that H makes one.

32. In THE INTERMITTENT MOTION shown in *fig.* 81., if C contain 4 teeth and D 40, what part of a revolution will D describe during the time that C makes 2 revolutions?

Ans. One-fifth of a revolution.

33. Supposing the wheel C, in the last problem, to revolve uniformly, and that C and D have equal radii, what will be the interval of rest of the wheel D as compared with the duration of its motion?

Ans. The duration of rest will be nine times that of motion.

34. If the diameter of the ECCENTRIC CROWN WHEEL A (see *fig.* 90.) is 10 in., at what distance from the centre must the axis *d c* be placed, so that its greatest angular velocity may be four times its least angular velocity, supposing the driver P to revolve uniformly? *Ans.* 3 in.

35. Required the velocity ratio of P and W in AN INCLINED PLANE (see *fig.* 91.), when AC=7 ft., and BC=2 ft.

Ans. $3\frac{1}{2}$.

If P descend 14 in., through what space will W ascend?

Ans. 4 in.

Show that the velocity ratio is the same for all positions of W on the plane.

36. What must be the inclination of the plane in the last problem, so that the vertical velocity of P may be double that of W? *Ans.* $\angle$ BAC=30°.

37. The length A B (see *fig.* 94.) of A MOVEABLE INCLINED

PLANE OR WEDGE is 6 in.; what must be the thickness B C, so that velocity P may be to velocity W as 3 is to 2?

Ans. 4 in.

If W move over $\frac{1}{2}$ in., through what space will P move?

Ans. $\frac{3}{4}$ in.

Show that P will move uniformly when W does so.

38. Construct the curve of A CAMB (see *fig.* 98.) so that the velocity of the rod C D may increase or decrease, as the case may be, according to an arithmetical progression, the angular velocity of the camb being constant.

39. Construct a wheel with WIPERS, &c., and determine the height of the lift of the rod or hammer, as the case may be (see *figs.* 100. and 101.).

40. What will be the length of the stroke of the rod B C (see *fig.* 103.) of A SWASH PLATE, when the distance of the rod from the axis D E is 3 in., and the plate A G has an inclination of 45° to the direction of its axis D E? *Ans.* 6 in.

What will be the position of the swash plate when the rod B C is in the middle of its stroke?

If the axis D E revolves uniformly, find the velocity of the rod at any given position of the plate.

41. Show that the length of the thread of A SCREW, cut upon a cylinder, is independent of the diameter of the cylinder; that when the inclination of the thread is 45°, the distance between the threads is equal to the circumference of the cylinder, and that in this case the whole length of the thread is equal to the length of the cylinder multiplied by $\sqrt{2}$. (See Art. **120.**)

42. Show how a thread may be cut upon a cylinder, so that the rod A B (see *fig.* 107.) may have a uniformly retarded motion, while the axis C D revolves uniformly.

43. If the distance between the threads of the screw in *fig.* 107. is 2 in., and the length of the handle P C is 30 in., what will be the ratio of the velocity of the extremity P of the handle to the velocity of the rod A B?

Ans. 94·248 : 1.

If the handle makes $2\frac{1}{2}$ revolutions, through what space will the rod be moved? *Ans.* 5 in.

If the extremity of the handle moves over 20 ft., through what space will the rod be moved? *Ans.* 2·54 in.

Show that when P moves uniformly, then the rod A B also moves uniformly.

44. In THE COMMON PRESS (see *fig.* 111.), if the length of the lever P is 3 ft., and the distance between the threads of the screw is $\frac{1}{2}$ in., what space must the extremity P pass over in order to move the press board B through the space of 2 in.? *Ans.* 75·4 ft. nearly.

45. In THE COMPOUND SCREW (see *fig.* 113.), let the distance between the threads of the large screw A = 1 in., and the distance between the threads of the small screw B = $\frac{7}{8}$ in., what will be the velocity ratio of P and W when the length of the handle P = 4 ft.? *Ans.* 2412.

46. In THE DIFFERENTIAL SCREW (see *fig.* 114.), let the thickness of the threads of the screw on *a b* or *e f* = $\frac{1}{2}$ in., what must be the thickness of the threads on *c d*, so that the nut *n* may move through the space of 1 in. in 20 revolutions of the handle A? *Ans.* $\frac{9}{20}$ in.

47. Required the velocity ratio of P and W in the endless screw (see *fig.* 115.), when the no. teeth in the whole circumference of the wheel K = 30, diameter of the axle C = 10 in., and the length of the handle P = 2 ft. 6 in. *Ans.* 180.

48. In the mechanism represented by *fig.* 116., let the radius A P of the handle = 30 in., the no. teeth in the first, second, and third wheels 40, 60, and 50, respectively, the no. teeth in the first and second pinions 5 and 10 respectively, and the diameter of the axle 6 in.; then $\frac{\text{velo. P}}{\text{velo. W}} = 24000$.

49. To investigate a general formula for THE COMPOUND MACHINE, of the preceding problem.

Let $D = 2\,AP$; N_1, N_2, N_3 = the no. teeth in the first, second, and third wheels respectively; n_1, n_2 = the no.

teeth in the first and second pinions respectively; and $d=$ the diameter of the axle.

Let the axle or the third wheel turn round once, then we have

no. turns of the first pinion or the first wheel $=\frac{N_3}{n_2}\cdot\frac{N_2}{n_1}$;

but the handle must turn round N_1 times in order to make the first wheel revolve once,

$$\therefore \text{ no. turns handle} = \frac{N_3}{n_2}\cdot\frac{N_2}{n_1}\cdot N_1;$$

$$\text{space described by P in one revo.} = \pi D,$$

$$\therefore \text{ total space described by P} = \frac{N_3}{n_2}\cdot\frac{N_2}{n_1}\cdot N_1\cdot\pi D,$$

$$\text{and space described by W} = \pi d,$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{space described by P}}{\text{space described by W}}$$

$$= \frac{\pi D\cdot N_1\cdot N_2\cdot N_3}{\pi d\cdot n_1\cdot n_2}$$

$$= \frac{D}{d}\cdot\frac{N_1\cdot N_2\cdot N_3}{n_1\cdot n_2}.$$

In the example given at page 79., $N_1=30$, $N_2=60$, $N_3=40$, $n_1=10$, $n_2=8$, $D=40$, and $d=5$,

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{40}{5}\times\frac{30\times 60\times 40}{10\times 8} = 7200.$$

50. Show how the thread *en* may be formed in A CONICAL SCREW (see *fig.* 117.), when the cone K*e*F is given, and space described by the rod CD in one revolution of the handle is also given.

51. What are the points of difference in the two forms of construction of the governor, exhibited in *figs.* 118 and 119.

52. What circumstances would render THE WATER REGULATOR, shown in *fig.* 120., inefficient.

53. In THE REGULATING DAMPER (see *fig.* 121.) the float F is heavier than the damper D. Why should this be the case? But when the water rises up to the float, the damper should preponderate. What should be the relative weights of the float and damper so that this may take place?

54. If the teeth on the wheel *e* (see *fig.* 123.) are $\frac{3}{4}$ in. apart, how many must there be of them in order to give 1-foot fall to the pestle *p*? *Ans.* 16.

55. If the wheel *c* (see *fig.* 124.) contains four teeth, whose distance apart is $1\frac{1}{4}$ in., what will be the length of the stroke of the rod A B? *Ans.* 5 in.

56. What determines the length of the stroke of the rod *n d* in the mechanism represented by *fig.* 126.?

57. In an up and down stroke of THE PISTON ROD *r h* (see *fig.* 129.) the crank, with its toothed wheel *p*, makes one revolution. Now if *p* contains 40 teeth, and the pinion *c* 5 teeth, how many revolutions will the fly-wheel *s* make in a double stroke of the piston? *Ans.* 8.

58. How may the motion of the wheel *m* (see *fig.* 130.) be reversed?

59. What fixes the length of THE CRANK in a steam engine (see *fig.* 182.)?

What advantage is there in having a long connecting rod?

60. In THE ECCENTRIC MOTION (see *fig.* 132.) the stroke of the pin F is equal to twice the distance of the axis A from the centre C of the wheel. Why?

61. To construct WATT'S PARALLEL MOTION, when CD and AB are not equal (see Art. 160.).

First, to find the point E (see *figs.* 203. and 204.) to which the air-pump rod must be attached, the radius rod CD being given.

Let AB be a portion of the great beam, turning on the centre A, CD the radius rod, turning on the centre C, and BD the connecting link. Let the rods be moved to the mean position A*bd*C, where the link *db* is perpendicular to A*b* and C*d*. Draw B*e* and D*c* perpendicular to AC, and produce the line *bd* until it intersects the link in E, then this will

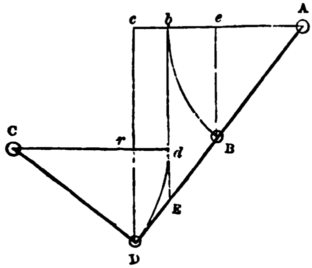


Fig. 203.

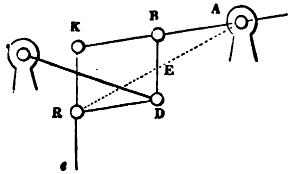


Fig. 204.

be the point which will most nearly move in a vertical line. The position of this point may be determined as follows:

Because the lines Be, Eb, and Dc, are parallel to each other, we have

$$\frac{\text{DE}}{\text{BE}}=\frac{cb}{eb}.$$

Let r=CD, R=AB, ∠DC$d=a$, and ∠BAb=A; then

$$cb=rd=r \text{ versin } a=r \sin^2 \frac{a}{2},$$

$$\text{and } eb=\text{R versin A}=\text{R} \sin^2 \frac{\text{A}}{2},$$

therefore by substitution

$$\frac{\text{DE}}{\text{BE}}=\frac{r \sin^2 \frac{a}{2}}{\text{R} \sin^2 \frac{\text{A}}{2}}=\frac{\text{R}}{r}\times\left(\frac{r \sin \frac{a}{2}}{\text{R} \sin \frac{\text{A}}{2}}\right)^2,$$

which expresses the ratio of the parts into which the link DB must be divided; but an approximate rule may be derived from this formula.

Now, in practice, the link DB deviates very little from the vertical; and then, in this case, the arc Dd is very nearly equal to the arc Bb; that is, $r\times a$ is very nearly equal to R × A; and as a and A are also small angles, $r \sin \frac{a}{2}=\text{R} \sin \frac{\text{A}}{2}$ very nearly; in this case, therefore, the formula simply becomes

$$\frac{\text{DE}}{\text{BE}}=\frac{\text{R}}{r},$$

$$\text{or, } AB : CD :: DE : BE \ldots (1),$$

or, by composition,

$$AB+CD : CD :: DB : BE,$$

$$\therefore BE = \frac{CD \cdot DB}{AB+CD} \ldots (2),$$

which gives the position of the point required.

Second, to find the length of the radius rod, when the divisions, AB and BK, on the beam are given (see *fig.* 203.).

From the similar triangles ABE and RDE, we have

$$RD \text{ or } BK : AB :: DE : BE,$$

therefore, by proportion (1),

$$BK : AB :: AB : CD,$$

$$\therefore CD = \frac{AB^2}{BK} \ldots (3),$$

which expresses the length of the radius rod as required.

(1.) Let CD=6 ft., AB=4 ft., and DB=2 ft., then by eq. (2),

$$BE = \frac{6 \times 2}{4+6} = 1\tfrac{1}{5} \text{ ft.}$$

(2.) Let AB=6 ft., and BK=5 ft., then, by eq. (3),

$$CD = \frac{6^2}{5} = 7\tfrac{1}{5} \text{ ft.}$$

62. In *fig.* 142., let the depth of the well =100 ft., diameter axle B=18 in., length of the lever G=6 ft.; if a man, turning the lever G, move at the rate of 5 miles per hour, in what time will he raise the bucket?

Space moved over by the bucket in 1 revo. of the axle B $=1\frac{1}{2} \times 3{\cdot}1416$,

$$\therefore \text{ no. revo. of the vertical axis } ec = \frac{100}{1\frac{1}{2} \times 3{\cdot}1416}.$$

Space described by G in 1 revo. $=12 \times 3{\cdot}1416$,

$\therefore$ no. revo. of the vertical axis *ec* per min.

$$= \frac{5280 \times 5}{60 \times 12 \times 3{\cdot}1416},$$

$$\therefore \text{ no. min. to raise the bucket } = \frac{100}{1\frac{1}{2} \times 3\cdot1416}$$

$$\div \frac{5280 \times 5}{60 \times 12 \times 3\cdot1416} = \frac{100 \times 60 \times 12}{1\frac{1}{2} \times 5280 \times 5} = 1\cdot82 \text{ min.}$$

63. Required the same as in the last problem, when the length of the lever G = 8 ft., the other data remaining the same. *Ans.* 2·42 min.

64. If the man, in prob. 62., exert a pressure of 20 lbs. upon the lever, how many cubic feet of water will he raise? *Ans.* 2·56.

65. Give a general investigation of problem 62.

66. If the horse, working a MILL (see *fig.* 143.), make 3 revolutions in a minute, how many revolutions will the shaft CD make in a second, supposing the bevel wheels *e* and C to contain 160 and 8 teeth respectively? *Ans.* one revolution.

67. If the diameter of the fly wheel *c* of THE POTTER'S LATHE (see *fig.* 144.) be 4 ft., and the diameter of the axle *d* be 6 in., how many revolutions will the block D make whilst the winch *r* is turned round once? *Ans.* 8.

68. In THE CRAB (see *fig.* 145.), let the length of the handle H = 20 in., the no. teeth in the pinion B = 8, the no. teeth in the wheel C = 72, and the diameter of the drum D = 18 in.; required the velocity ratio of the power and weight. *Ans.* 20.

Let D revolve round once, then

$$\text{no. revo. of the handle} = \frac{72}{8};$$

Space moved over by the weight attached to the rope *r* $= 18 \times 3\cdot1416$;

Space moved over by the power applied to the handle

$$= \frac{72}{8} \text{ times circum. handle } = \frac{72}{8} \times 2 \times 20 \times 3\cdot1416;$$

$$\therefore \frac{\text{velo. P}}{\text{velo. W}} = \frac{72}{8} \times 2 \times 20 \times 3{\cdot}1416 \div 18 \times 3{\cdot}1416$$

$$= \frac{2 \times 20 \times 72}{18 \times 8}.$$

Now we may readily generalise the form of this result, for it will be observed that 2×20 is twice the length of the handle, 18 is the diameter of the drum, 72 is the no. teeth in the wheel, and 8 is the no. teeth in the pinion; hence we have

$$\frac{\text{velo. P}}{\text{velo. W}} = \frac{\text{twice length handle} \times \text{no. teeth in wheel}}{\text{diam. drum} \times \text{no. teeth in pinion}}.$$

It will also be observed that this velocity ratio always gives us the advantage gained by the machine, the friction, &c., being neglected. Thus, in the present case the velocity ratio being 20, the advantage of pressure gained by the machinism will also be 20.

69. In the preceding problem, if the length of the handle is 7 times the radius of the drum, and the no. teeth in the wheel also 7 times the no. teeth in the pinion, then it is required to show, that $\frac{\text{velo. P}}{\text{velo. W}} = 7^2$ or 49.

70. If the length of the handle in problem 68., be n times the radius of the drum, and the no. teeth in the wheel m times the no. teeth in the pinion, then the velocity ratio of P and W is equal to $n \times m$. Required the proof.

71. Why are the handles of THE CRAB placed in opposite directions?

72. In what respects does the construction of *the gib crane* differ from that of *the crab?* What is the peculiarity in the construction of THE HAND JACK?

73. In THE COMMON LATHE (see *fig.* 149.), if the treadle T makes an up and down stroke, how many revolutions will the mandrill A make, supposing the diameters of D and E to be 3 ft. and 5 in. respectively? *Ans.* $7\frac{1}{5}$.

74. In *the self-acting slide rest* (see *fig.* 150.), if the wheel *n* contains 10 teeth, and the distance between the threads of the screw, which gives a longitudinal motion to the saddle F, is $\frac{4}{5}$ of an inch, through what space will the cutting tool *r o* be carried at each action of the hoop *e*?

Here, in one entire revolution of the wheel *n*, the tool *r o* will be moved through a space equal to the distance between the threads of the screw, therefore the space moved over by the cutting tool in one revolution of the bar C will be $\frac{1}{10}$ of $\frac{4}{5}$ in. $=\frac{2}{25}$ in.

75. If the length of the bar C to be turned, in the last problem, is 4 ft., and if it makes 12 revolutions in a minute, in what time will the work be completed? *Ans.* 50 min.

76. In *fig.* 151., let the number of teeth in the wheel E=5, the number in the wheel D=20, the number in the wheel A=12, and the distance between the teeth on the rack or wheel A=$\frac{2}{3}$ in.; required the distance between the threads of the spiral described, by the point *e*, on the cylinder.

Here, in one revolution of the cylinder C, the axis of the wheels, D and A, will describe $\frac{1}{4}$ of a revolution, and therefore the rack will be raised the space of 3 teeth; that is, the point *e* will be raised 3 times $\frac{2}{3}$ in.=2 in., which will be the distance between the threads of the spiral.

77. Required the same as in the last problem, when the no. teeth in the wheel E=6, number in D=18, number in A=9, and the distance between the teeth on the rack = $\frac{1}{2}$ in. *Ans.* $1\frac{1}{2}$ in.

78. In the machine for CUTTING SCREWS (see *fig.* 152.), let the no. teeth on the wheel A=30, no. teeth on the wheel D=10; and the distance between the threads of the screw which moves the saddle F=$\frac{1}{2}$ in.; required the distance between the threads of the screw which will be cut upon the rod E.

Let the wheel A, with its axis E, make one revolution, then we have

$$\text{no. revo. wheel D}=\frac{30}{10}=3;$$

∴ Distance which the point c is moved $=3$ times $\frac{1}{2}$ in. $=1\frac{1}{2}$ in., which is the distance between the threads cut on the rod E.

79. Required the same as in the last problem, when the no. teeth on A$=16$, no. on D$=8$, and the distance between the threads of the screw which moves the saddle$=\frac{1}{4}$ in.

Ans. $\frac{1}{2}$ in.

80. Required the proportional number of teeth in the wheels A and D (see *fig.* 152.), so that the distance between the threads on the rod E may be $1\frac{1}{2}$ times the distance between the threads on the axis of D. *Ans.* As 3 is to 2.

81. In the SCREW-CUTTING MACHINE, required the same as in problem 78., when $n=$ the no. teeth on A, $n_1=$ the no. on D, $t=$ the thickness of the threads on the axis E, and $t_1=$ the thickness of the threads on the axis of D.

Let A make one revolution, then

$$\text{no. revo. D} = \frac{n}{n_1},$$

$$\therefore \text{distance point } c \text{ is moved over} = \frac{n}{n_1} \text{ times } t_1,$$

$$\text{that is, } t = \frac{n}{n_1} \cdot t_1 \ldots (1),$$

which is the expression required.

From this equality we have

$$\frac{t}{t_1} = \frac{n}{n_1} \ldots (2),$$

that is, *the thicknesses of the threads are in the ratio of the number of teeth on their respective wheels.*

If t_1 in eq. (2) be constant, then

$$t \propto \frac{n}{n_1},$$

that is, *the thickness of the threads on the rod* E *varies with the ratio of the number of teeth on the two wheels.*

If n_1 as well as t_1 be constant, then

$$t \propto n,$$

that is, the thickness of the thread on the rod E varies with the no. teeth on its wheel A.

In the place of having the thickness of the threads of the screw given, let k = the no. threads in one inch of E, and k_1 = the no. threads in one inch of D, then

$$\frac{1}{k}=t, \text{ and } \frac{1}{k_1}=t_1,$$

substituting these values in eq. (2), we have

$$\frac{k_1}{k}=\frac{n}{n_1} \ldots (3),$$

$$\therefore k=\frac{n_1 k_1}{n} \ldots (4).$$

Let there be an intermediate pinion and wheel between the wheels A and D, and let the pinion on which A acts contain r_1 teeth, and the wheel which acts on D contain r teeth, then the velocity ratio of the axis D will be increased, from this cause, by the ratio $\frac{r}{r_1}$, hence in this case eq. (4) becomes

$$k=\frac{n_1 r_1 k_1}{n r} \ldots (5).$$

Here k is called *the pitch* of the screw.

82. In THE HAND DRILL (see *fig.* 154.), let the no. teeth in the bevel wheel A=27, and the no. teeth in B=15; whilst the handle H makes 5 revolutions, how many will the drill p make? *Ans.* 9.

83. In THE SHEARS for cutting metal (see *fig.* 155.), let the distance EE of the edges, when the shears are open $=\frac{3}{4}$ in., DE=6 in., and De=4 ft.; required the eccentricity of the wheel A, so that the opening of the shears may be just closed at each stroke.

Here the velocity of e is 8 times that of E, therefore the length of the stroke described by e must be 8 times $\frac{3}{4}$ in., or 12 inches; but the eccentricity of the wheel is equal to half the length of the stroke, therefore the eccentricity of the wheel A must be $\frac{1}{2}$ of 12 inches, or 6 inches.

84. Required the same as in the last example, when De=3 ft., the other data remaining the same. *Ans.* $4\frac{1}{2}$ in.

85. In the CORN MILL (see *fig.* 160.), let the no. teeth in the face wheel C=40, and the no. staves in the trundle D=12; how many revolutions will the stone make whilst the winch H makes 3? *Ans.* 10.

86. In THE SAW MILL (see *fig.* 161.), let one tooth of ratchet wheel E be pushed round at each revolution of the fly wheel W, and let the no. ratchet teeth =15, the no. teeth in the pinion R=5, and their distance apart =2 in.; required the length of the cut made by the saw at each downward stroke.

At each downward stroke of the saw the wheel E will be moved over $\frac{1}{15}$ of its circumference; but in one revolution of E the rack *g k* will be advanced 5 times 2 in., or 10 inches; therefore in $\frac{1}{15}$ of a revolution it will be advanced $\frac{1}{15}$ of 10 inches, or $\frac{2}{3}$ in., which is the length of the saw-cut required.

87. Required the same as in the last problem, when the ratchet wheel contains 25 teeth. *Ans.* $\frac{2}{5}$ in.

88. If the horizontal wheel A in THE SMOKE JACK (see *fig.* 163.) makes 18 revolutions in a minute, how many revolutions will the wheel E make in the same time, supposing the no. staves in the trundle T=5, and the no. teeth in the face wheel F=9? *Ans.* 10.

89. In the mechanism for A CLOCK (see *fig.* 164.), let the no. teeth on the wheel C=72, the no. teeth on the pinion G=8; it is required to determine the ratio of the no. teeth on the wheels E and F, so that whilst the axis B D revolves in an hour, the axis F J may revolve in a minute.

$$Ans.\ \frac{\text{no. teeth on E}}{\text{no. teeth on F}}=\frac{20}{3}.$$

90. If the area of the piston P in THE FORCING PUMP (see *fig.* 166.) is 30 sq. in., and the length of the stroke 2 ft., how many cubic feet of water will be raised by 12 downward strokes of the piston? *Ans.* 5 c. ft.

91. If the sprocket wheel Q in THE CHAIN PUMP (see *fig.* 172.) contain 12 teeth. the distance between the teeth being

4 inches, what quantity of water will be raised per minute, supposing the section of the barrel DC to be 40 sq. in., and the number of revolutions performed by the wheel Q per minute to be 24? *Ans.* $26\frac{2}{3}$ c. ft.

Space moved over by the piston per min. $=12 \times 4 \times 24$ in. $=96$ ft.

$$\therefore \text{ no. c. ft. water raised} = \frac{40}{144} \times 96 = 26\tfrac{2}{3}.$$

92. Required the same as in the last problem, when the section of the barrel is 48 sq. in. *Ans.* 32 c. ft.

93. In THE CRANK PUMP (see *fig.* 173.), let the no. teeth on the pinion $C=8$, the no. on the wheel $D=30$; it is required to find the number of single strokes performed by each piston rod whilst the winch A makes 15 revolutions. *Ans.* 8.

94. If the length of the stroke of the piston in A BEAM ENGINE (see *fig.* 182.) be 3 ft., what space will the extremity of the crank describe in 6 double strokes of the piston? *Ans.* 56·55 ft.

1. To show that when the great beam LL is horizontal, the crank N is not so.

2. If $r=$ the length of the crank, $R=$ one half the length of the great beam, and $A=$ the angle described by the beam in one stroke, then it is required to show that

$$\sin\frac{A}{2}=\frac{r}{R} \ldots (1).$$

It will be observed, that the crank and connecting rod should be in the same straight line at the top and bottom of the stroke.

3. *To find the velocity ratio of the crank and great beam.*

In *fig.* 17., let $AD=R$ represent one half of the great beam, $CP=r$ the crank, the link AP being the connecting rod, then putting $\beta=\angle CPQ$, and $\beta_1=\angle DAR$, we have from eq. (1), Art. 31.,

$$\frac{\text{ang. velo. CP}}{\text{ang. velo. DA}}=\frac{DR}{CQ}=\frac{R\sin\beta_1}{r\sin\beta};$$

$$\therefore \frac{r\times\text{ang. velo. CP}}{R\times\text{ang. velo. DA}}=\frac{\sin\beta_1}{\sin\beta}, \text{ or}$$

$$\frac{\text{velo. crank}}{\text{velo. beam}}=\frac{\sin\beta_1}{\sin\beta}\ \ldots\ (2).$$

When β_1 is constant and equal to 90°, which it is very nearly when the connecting rod is very long as compared with the length of the crank (see *fig.* 182), then this equality becomes

$$\frac{\text{velo. crank}}{\text{velo. beam}}=\frac{1}{\sin\beta}\ \ldots\ (3);$$

this velocity ratio will be a maximum when $\beta=0$, and a minimum when $\beta=90°$; that is, the velocity of the crank will be a maximum when it is in its dead points, and a minimum when it is at right angles to the connecting rod.

95. In THE SLIDE VALVE motion represented in *fig.* 187., let the eccentricity of the wheel G$=1\frac{1}{2}$ in., HI$=2\frac{1}{2}$ times kI; required the length of the stroke of the slide valve.

Stroke of the rod Gk=2 times $1\frac{1}{2}$ in.=3 in.;

$$\frac{\text{velo. H}}{\text{velo. }k}=\frac{\text{HI}}{k\text{I}}=2\tfrac{1}{2};$$

but the space described by k=3 in.,

∴ space described by H$=2\frac{1}{2}$ times 3 in.$=7\frac{1}{2}$ in.,

which is the length of the stroke of the valve.

96. Required the same as in the last problem, when the eccentricity is 2 in., and HI$=1\frac{2}{3}$ times kI. *Ans.* $6\frac{2}{3}$ in.

97. Required the ratio of kI and HI, when the eccentricity is 4 inches, and the stroke of the valve is 6 inches.

Ans. HI$=1\frac{1}{2}$ times kI.

98. To determine the various relations of position, &c., of THE CRANK AND PISTON in the engine represented in *fig.* 187.

Let l=DE, the length of the connecting rod;

l_1=PD, the length of the piston rod;

r=FE, the length of the crank;

a= ∠FED, the angle which the crank makes with the direction of the connecting rod;

k=DF, the distance of the axis of the crank from the extremity of the piston rod;

h= the corresponding height of the stroke of the piston, Then we have

1. *Length of the stroke of the piston* $=2r$.

2. *To find the position of the crank when the piston is in the middle of its stroke.*

When the piston is at the bottom of the stroke, its distance from $F = EF + ED + PD = r + l + l_1$;

$\therefore$ when the piston is at the middle of its stroke,

$$DF = \overline{r + l + l_1} - \overline{r + l_1} = l;$$

that is, in this position of the piston, DF = DE, and DEF is an isosceles triangle. In this case we have

$$l \times \cos. a = \frac{r}{2},$$

$$\therefore \cos a = \frac{r}{2l} \ldots (1).$$

3. *To find the position of the crank at any point of the stroke of the piston.*

From a well known relation of the sides of the triangle EDF, we have

$$\cos a = \frac{r^2 + l^2 - k^2}{2rl} \ldots (2);$$

but $k = r + l - h$; therefore, by substitution, we have

$$\cos a = \frac{r^2 + l^2 - (r + l - h)^2}{2rl} \ldots (3).$$

Eqs. (2) and (3) are the general equations required.

When h = one-half the stroke of the piston $= r$, then eq. (3) becomes

$$\cos a = \frac{r}{2l},$$

which is the same as eq. (1).

When $a = 90$, $\cos a = 0$, and then from eq. (3)

$$(r + l - h)^2 = r^2 + l^2,$$

$$\therefore h = r + l - \sqrt{r^2 + l^2} \ldots (4),$$

which gives the position of the piston, when the crank is at right angles to the connecting rod. This expression is obviously less than r or half the stroke of the piston; therefore the crank is at right angles with the connecting rod before the piston has arrived at the middle of its upward stroke.

When the crank is horizontal, or at right angles to the direction of the piston rod, we have from the right-angled triangle DFE,

$$\text{DF} = \sqrt{\text{DE}^2 - \text{FE}^2}, \text{ that is,}$$

$$k = \sqrt{l^2 - r^2},$$

$$\text{but } k = r + l - h,$$

$$\therefore r + l - h = \sqrt{l^2 - r^2},$$

$$\therefore h = r + l - \sqrt{l^2 - r^2} \ldots (5),$$

which gives the length of the stroke of the piston when the crank is at right angles to the direction of the piston rod.

4. *To find the velocity ratio of the crank and piston.*

Differentiating eq. (2), and reducing, we find

$$\frac{r \times d\alpha}{dk} = \frac{k}{l \sin \alpha}, \text{ that is,}$$

$$\frac{\text{velo. crank}}{\text{velo. piston}} = \frac{k}{l \sin \alpha} \ldots (6).$$

Let $\beta = \angle$ EFD, the angle which the crank makes with the direction of the piston rod; then $\frac{k}{\sin \alpha} = \frac{l}{\sin \beta}$, hence we have by substituting in eq. (6),

$$\frac{\text{velo. crank}}{\text{velo. piston}} = \frac{1}{\sin \beta} \ldots (7),$$

which is the same result as that obtained in eq. (3) problem 94.

99. Given the angle, DOB $= \alpha$, which the axes of two bevel wheels in and im make with each other (see *fig.* 61.), to find the angle at the vertex of each cone.

Let $\beta = \angle$ DOi, the semi-angle at the vertex of the cone nio, and let $m = \frac{in}{im}$, the ratio of the diameters, then

$$in = \text{o}i \times \sin \beta \times 2,$$
$$im = \text{o}i \times \sin (\alpha - \beta) \times 2,$$

$$\therefore \frac{\sin \beta}{\sin (\alpha - \beta)} = \frac{in}{im} = m,$$

$$\therefore \frac{\sin\beta}{\sin\alpha\,.\cos\beta-\cos\alpha\,.\sin\beta}=m,$$

$$\therefore \tan\beta=\frac{\sin\alpha}{\frac{1}{m}+\cos\alpha}.$$

If the axes are at right angles to each other, $\alpha=90°$, and then

$$\tan\beta=m.$$

100. Required the LEAST NUMBER OF AXES IN A TRAIN OF WHEELS which shall cause the last axis to revolve 140 times as fast as the first axis, allowing that none of the drivers can contain more than 60 teeth, and none of the followers less than 6.

Each pair of wheels cannot increase the motion more than 10 times, because $\frac{60}{6}=10$; therefore the number of pairs of wheels, containing 60 and 6 teeth respectively, cannot exceed 2, because 2 such pairs would increase the motion 100 times, and 3 such pairs would increase it 1000 times, whereas it has only to be increased 140 times. Let N_3=the no. teeth in the last driver, and n_3=the no. teeth in the last follower; then

$$\frac{60}{6}\times\frac{60}{6}\times\frac{N_3}{n_3}=140,$$

$$\therefore \frac{N_3}{n_3}=\frac{7}{5},$$

therefore if $N_3=7$, $n_3=5$, and the no. pairs of wheels$=3$; but the no. axes is always one more than the no. pairs; therefore the least number of axes$=3+1=4$.

101. To determine the LEAST NUMBER OF TEETH IN A TRAIN requisite to cause the last axis to revolve m times as fast as the first.

Let p = the no. pairs of wheels, N = the no. teeth in the drivers, n_1 = the no. teeth in the followers; then

$$\left(\frac{N}{n}\right)^p = m,$$

or putting $x = \frac{N}{n}$,

$$x^p = m, \text{ and } \therefore p = \frac{\log m}{\log x}.$$

no. teeth in the whole train $= p(n + N) = np\left(1 + \frac{N}{n}\right) = np(1 + x)$ $= \frac{n \log m (1 + x)}{\log x} =$ a minimum.

$$\therefore \frac{1 + x}{\log x} = \text{a minimum},$$

$$\therefore \log x - \frac{1 + x}{x} = 0, \text{ whence } x = 3{\cdot}59,$$

which is the ratio of the no. teeth in the driver to the no. in its follower.

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